DECEMBER 1960

Volume 196 Part 4

Established 1869
Incorporated by Royal Charter 1899

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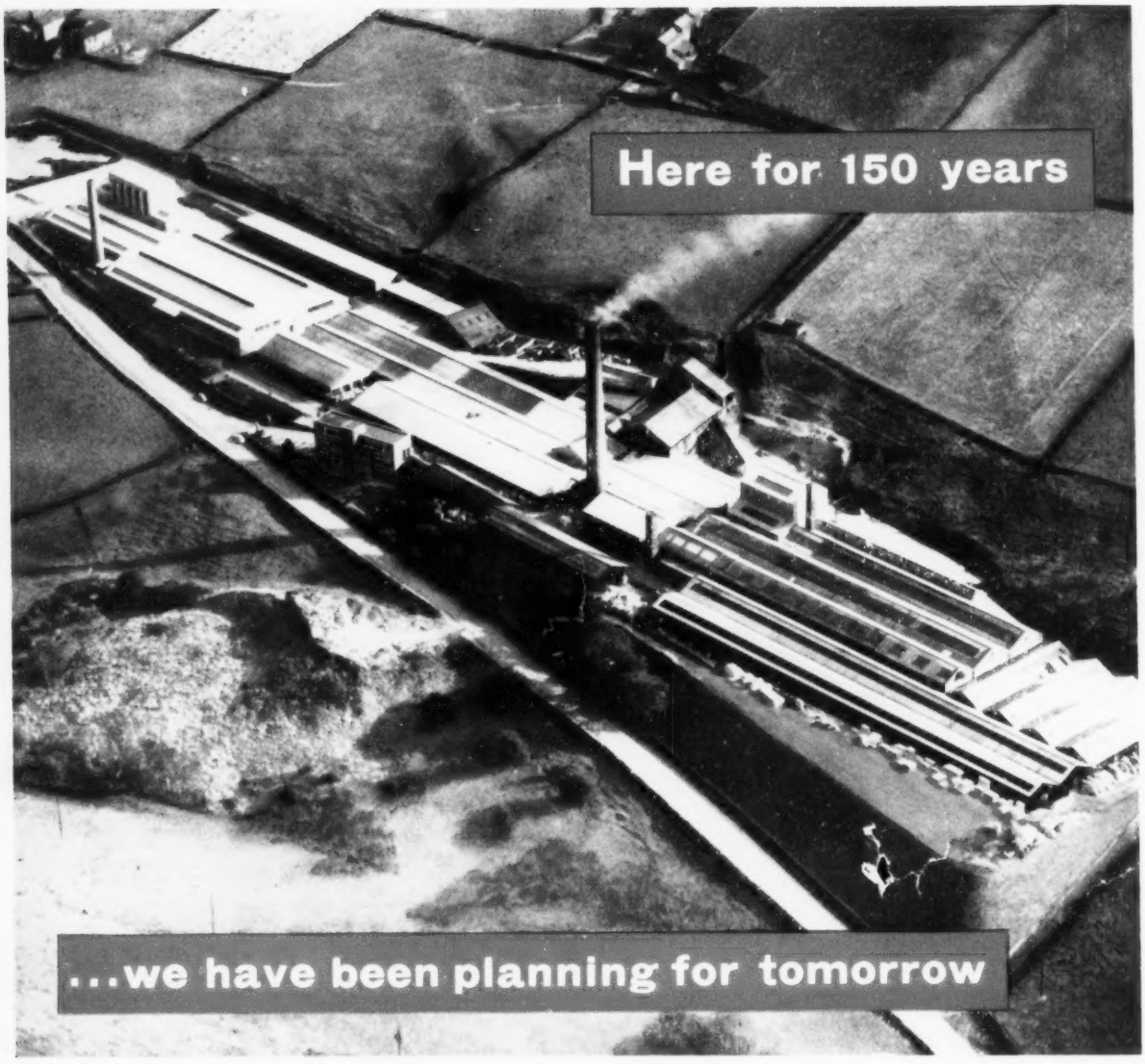

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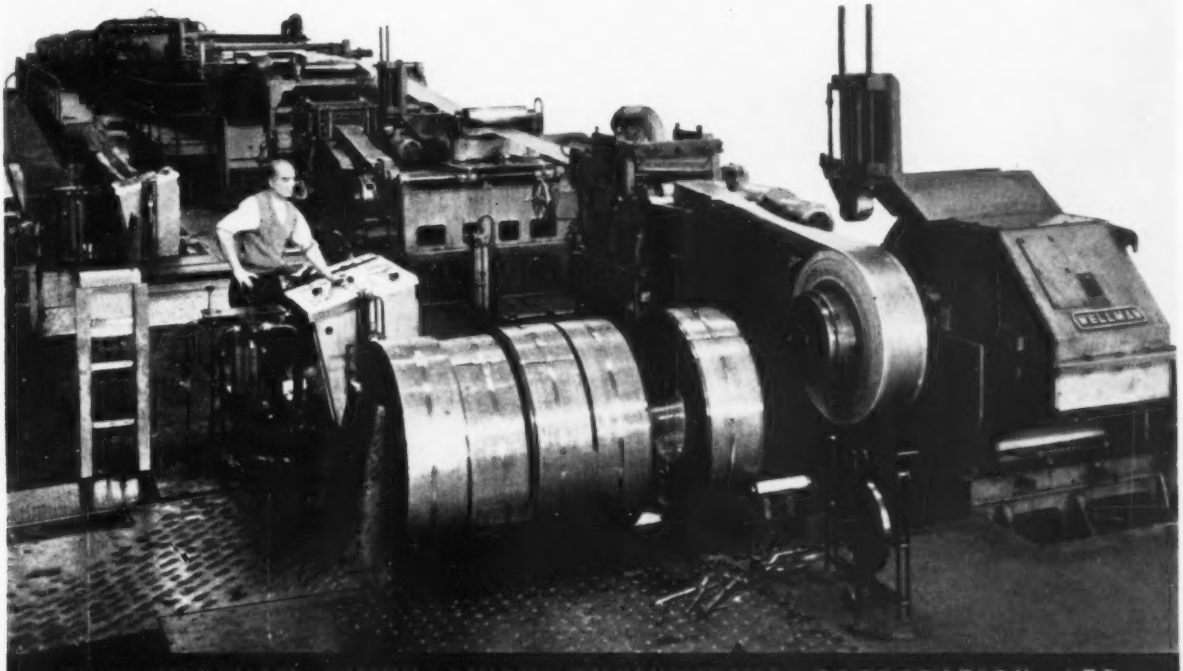
Auxiliary
Rolling Mill Equipment

Below is illustrated the exit end of a Wellman Multi-Strand Continuous Pickle Line, for processing low carbon and mild steel hot rolled strip, installed at the Works of a large Sheffield manufacturer. The line is at present operating with two strands, but will ultimately be arranged for four-strand simultaneous processing.

This is one of the numerous Wellman installations in both the United Kingdom and Overseas, designed for the continuous processing of low carbon, mild, silicon and stainless steels in a wide variety of gauges and widths.



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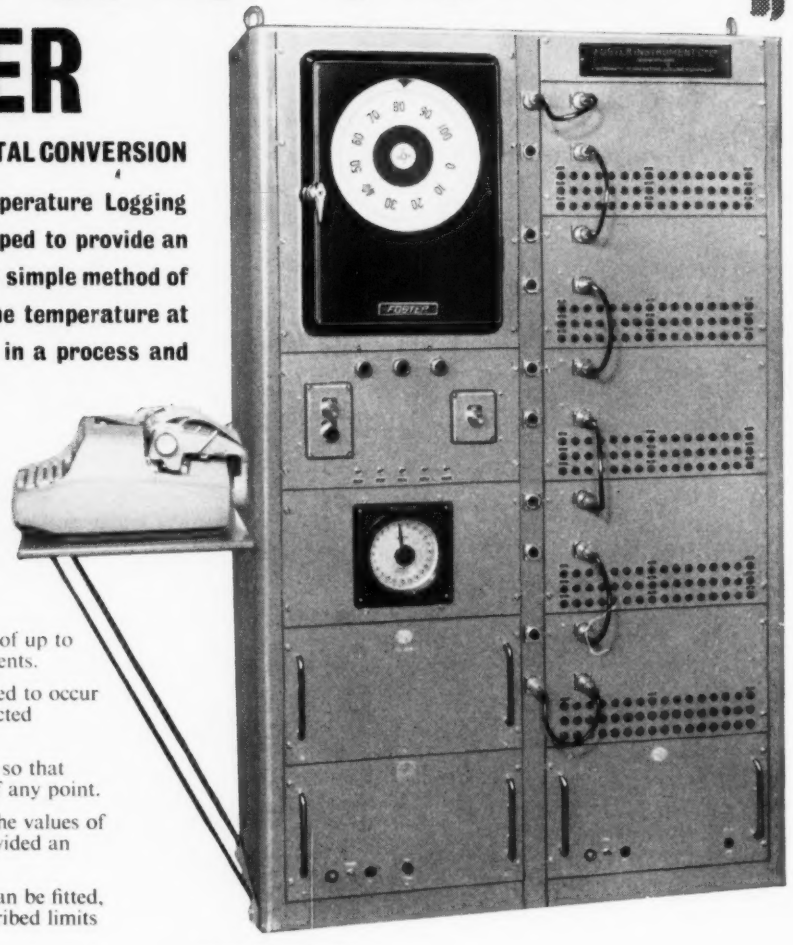
The Foster Automatic Temperature Logging Equipment has been developed to provide an inexpensive and technically simple method of automatically measuring the temperature at a large number of stations in a process and of recording the results in digital form.



SOME OF THE CAPABILITIES OF THIS EQUIPMENT

Indicates and/or logs the temperatures of up to 208 thermocouples or Resistance Elements.

The scanning of stations can be arranged to occur at selected time intervals and for a selected number of the measuring points.

An external recorder can be connected so that a continuous record can be obtained of any point.

The equipment can be used to record the values of quantities other than temperature, provided an appropriate sensing element is used.

Visual and/or audible alarm contacts can be fitted, or if the readings are outside the prescribed limits they can be printed in red.

The equipment can be made transportable.

The typewriter can be replaced by:

1. a tape punching machine
2. an in-line digital indicator
3. a column numerical printing machine

APPLICATION

The equipment can be used with advantage in any process which the measurement at a large number of stations has to be recorded manually.

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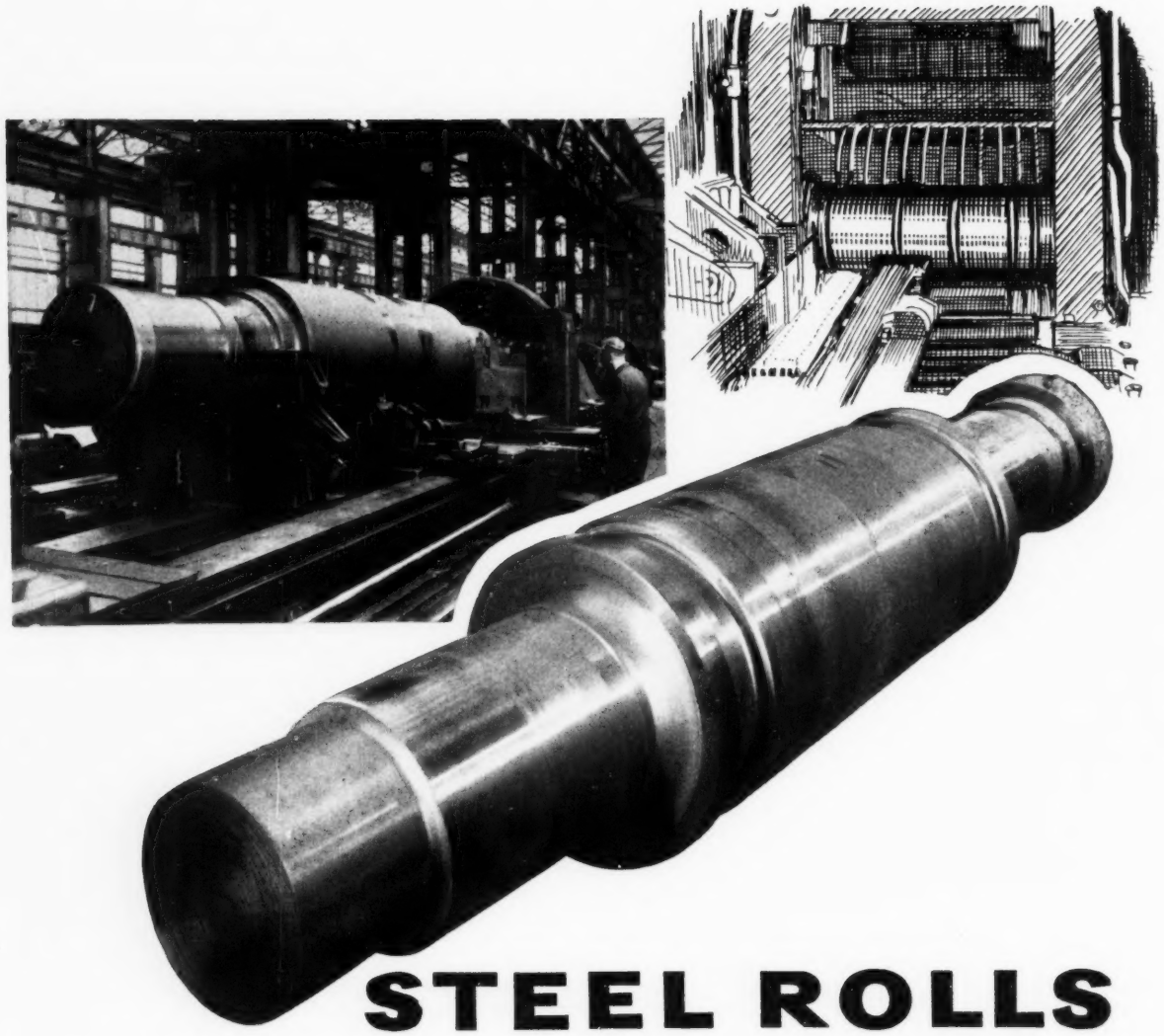

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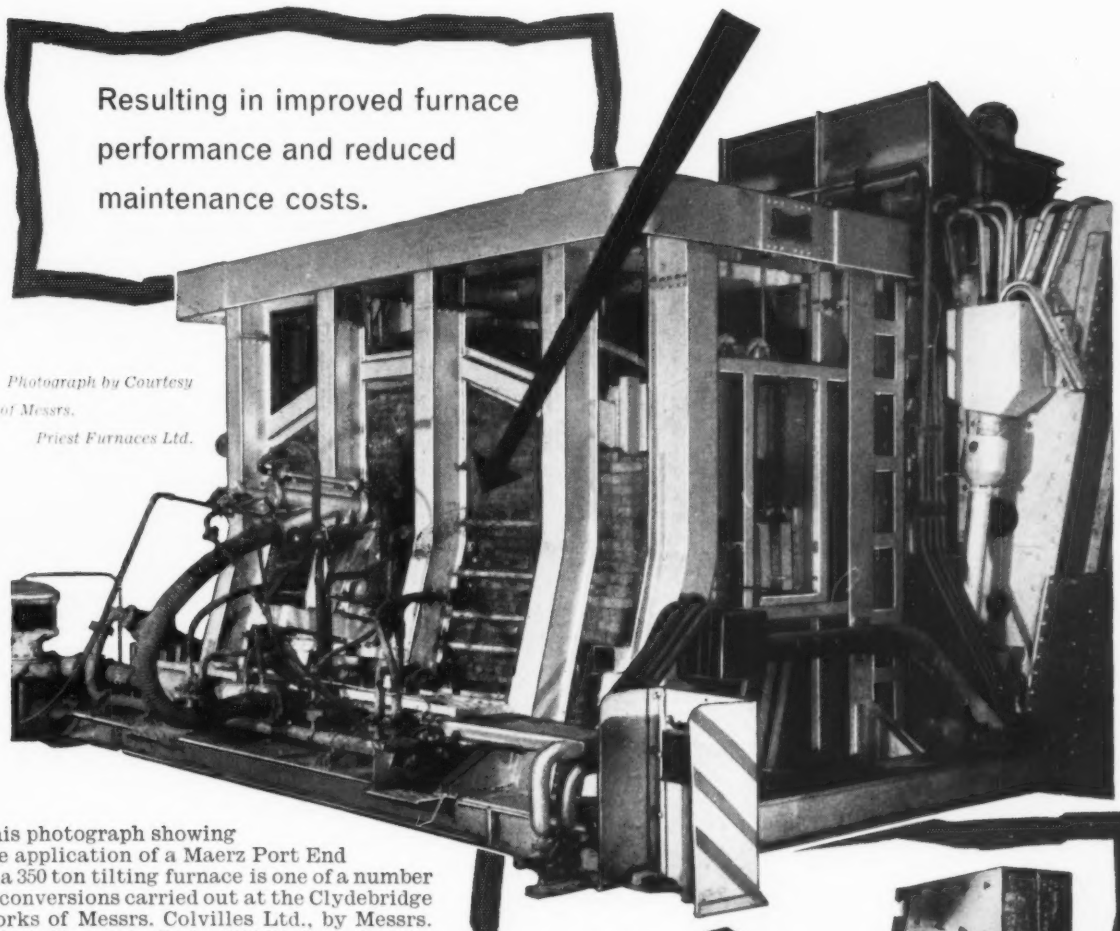
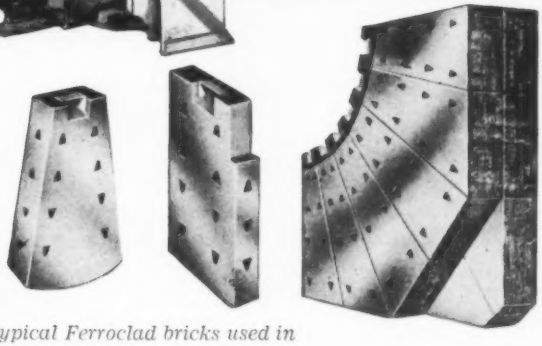


Photograph by Courtesy of Messrs. Priest Furnaces Ltd.

This photograph showing the application of a Maerz Port End to a 350 ton tilting furnace is one of a number of conversions carried out at the Clydebridge Works of Messrs. Colvilles Ltd., by Messrs. Priest Furnaces Ltd., Middlesbrough. The port end is constructed entirely of Ferroclad '70' metal-cased chemically bonded basic refractories.



Typical Ferroclad bricks used in Maerz Port End construction

G.R. Ferroclad bricks are manufactured in a range of four main qualities to suit requirements—chrome (Ferroclad 10), chrome-magnesite (Ferroclad 30), magnesite-chrome (Ferroclad 70) and magnesite (Ferroclad 100). Full particulars and recommendations for the application of Ferroclad bricks is available on request.

The manufacture of Ferroclad bricks is covered by British Patent No. 546,220 and other additions including the "Ferroclip", the "Tabhanger" and the 'EE' are covered by British Patent Nos. 546,220, 600,630, 749,491, 778,047, and 778,048.

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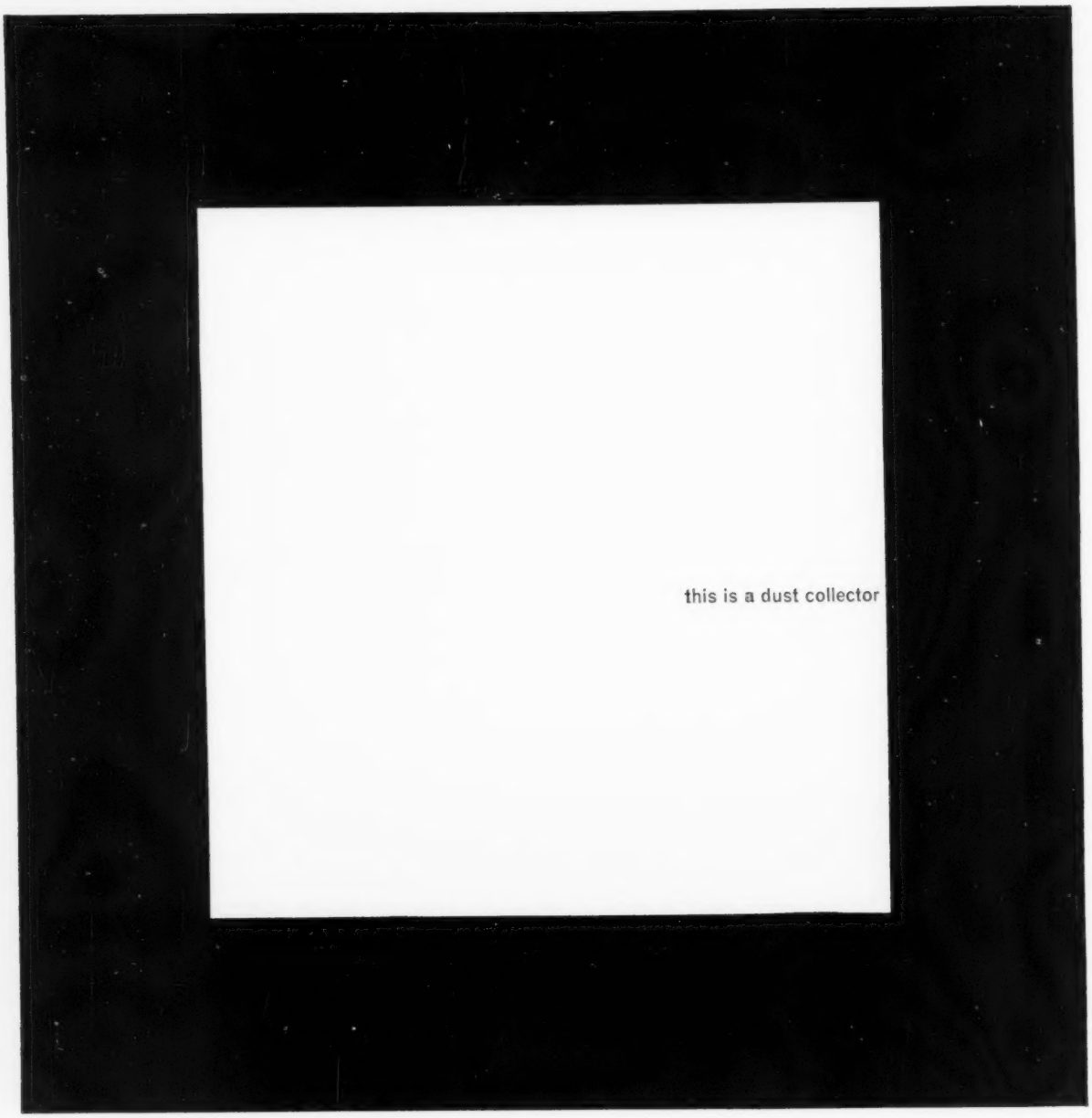

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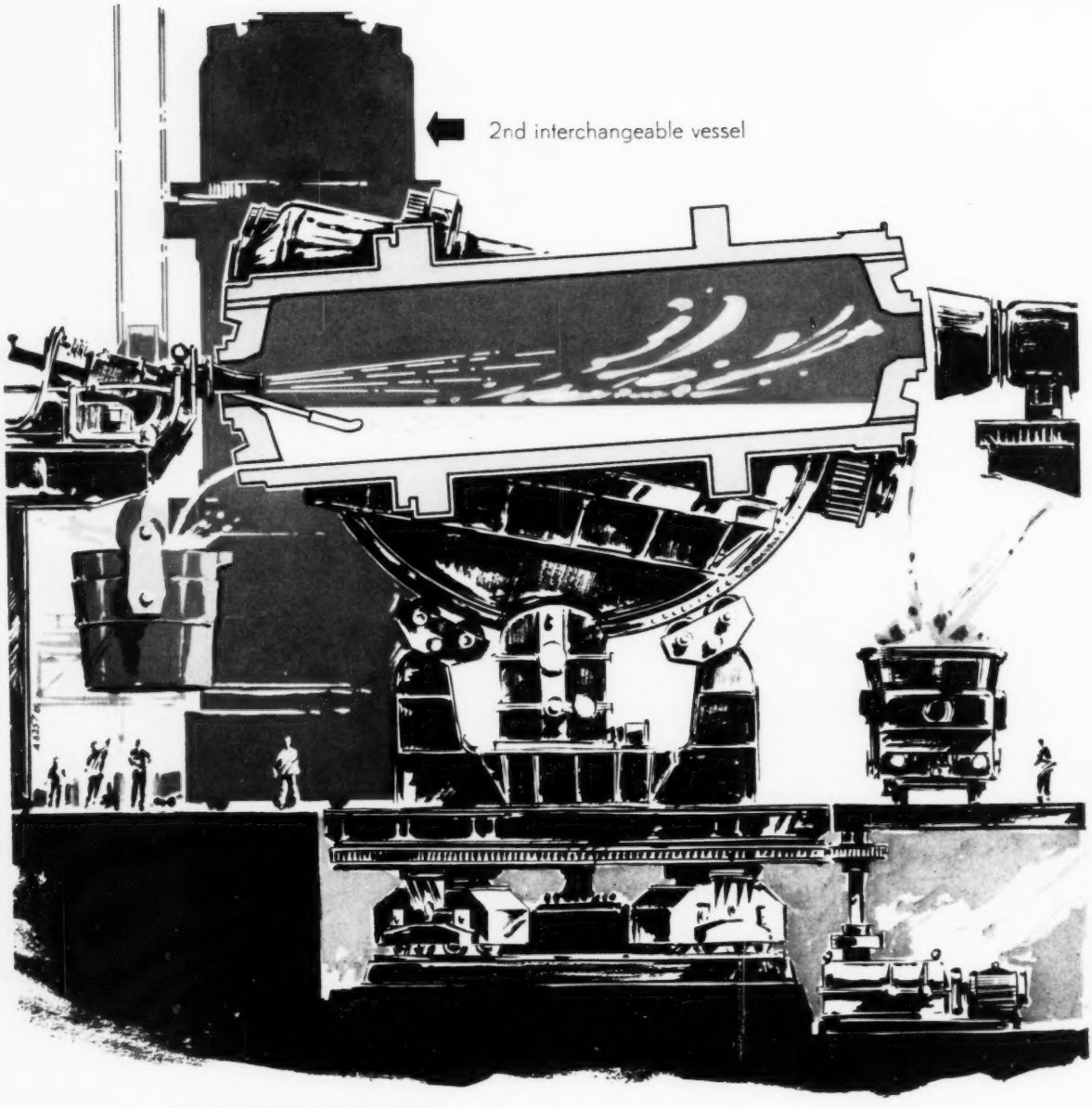

DEMAG

Cost-conscious Engineering

Among the latest methods of rational steel production is the Rotor Process in which hot metal is refined into steel of open-hearth quality with the help of oxygen. The furnace is mounted on a tilting cradle so that two interchangeable vessels can be employed. Production need thus not be interrupted when relining is necessary. DEMAG has designed and constructed to its own system plants of 75 to 100 ton capacity for European and overseas customers.

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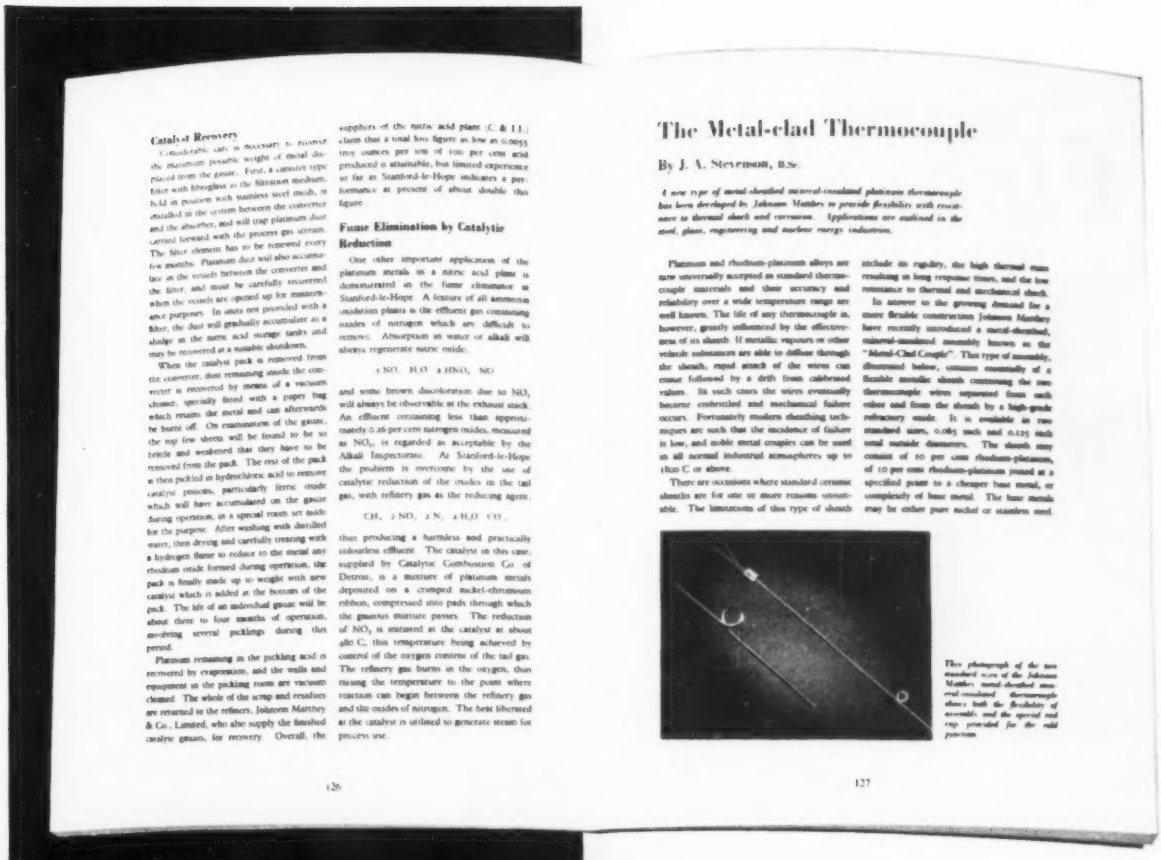

Catalyst Recovery

Considerable care is necessary to recover the maximum possible weight of metal displaced from the gauze. First, a canister type filter with fibreglass as the filtration medium, held in position with stainless steel mesh, is installed in the system between the converter and the absorber, and will trap platinum dust carried forward with the process gas stream. The filter element has to be renewed every few months. Platinum dust will also accumulate in the vessels between the converter and the filter, and must be carefully recovered when the vessels are opened up for maintenance purposes. In units not provided with a filter, the dust will gradually accumulate as a sludge in the nitric acid storage tanks and may be recovered at a suitable shutdown.

When the catalyst pack is removed from the converter, dust remaining inside the converter is recovered by means of a vacuum cleaner, specially fitted with a paper bag which retains the metal and can afterwards be burnt off. On examination of the gauze, the top few sheets will be found to be so brittle and weakened that they have to be removed from the pack. The rest of the pack is then pickled in hydrochloric acid to remove catalyst poisons, particularly ferric oxide which will have accumulated on the gauze during operation, in a special room set aside for the purpose. After washing with distilled water, then drying and carefully treating with a hydrogen flame to reduce to the metal any rhodium oxide formed during operation, the pack is finally made up to weight with new catalyst which is added at the bottom of the pack. The life of an individual gauze will be about three to four months of operation, involving several picklings during this period.

Platinum remaining in the pickling acid is recovered by evaporation, and the walls and equipment in the pickling room are vacuum cleaned. The whole of the scrap and residues are returned to the refiners, Johnson Matthey & Co., Limited, who also supply the finished catalyst gauzes, for recovery. Overall, the suppliers of the nitric acid plant (C. & I.) claim that a total loss figure as low as 0.0055 troy ounces per ton of 100 per cent acid produced is attainable, but limited experience so far as Stanford-le-Hope indicates a performance at present of about double this figure.

Fume Elimination by Catalytic Reduction

One other important application of the platinum metals in a nitric acid plant is demonstrated at the fume eliminator at Stanford-le-Hope. A feature of all ammonia oxidation plants is the effluent gas containing oxides of nitrogen which are difficult to remove. Absorption in water or alkali will always regenerate nitric oxide:

$$3\,NO_2 + H_2O \rightarrow 2\,HNO_3 + NO$$

and some brown discoloration due to NO_2 will always be observable at the exhaust stack. An effluent containing less than approximately 0.26 per cent nitrogen oxides, measured as NO_2, is regarded as acceptable by the Alkali Inspectorate. At Stanford-le-Hope the problem is overcome by the use of catalytic reduction of the oxides in the tail gas, with refinery gas as the reducing agent:

$$CH_4 + 2\,NO_2 \rightarrow 2\,N_2 + 2\,H_2O + CO_2$$

thus producing a harmless and practically colourless effluent. The catalyst in this case, supplied by Catalytic Combustion Co. of Detroit, is a mixture of platinum metals deposited on a crimped nickel-chromium ribbon, compressed into pads through which the gaseous mixture passes. The reduction of NO_2 is initiated at the catalyst at about 480 C, this temperature being achieved by control of the oxygen content of the tail gas. The refinery gas burns on the oxygen, thus raising the temperature to the point where reaction can begin between the refinery gas and the oxides of nitrogen. The heat liberated at the catalyst is utilised to generate steam for process use.

The Metal-clad Thermocouple

By J. A. Stevenson, B.Sc.

A new type of metal-sheathed mineral-insulated platinum thermocouple has been developed by Johnson Matthey to provide flexibility with resistance to thermal shock and corrosion. Applications are outlined in the steel, glass, engineering and nuclear energy industries.

Platinum and rhodium-platinum alloys are now universally accepted as standard thermocouple materials and their accuracy and reliability over a wide temperature range are well known. The life of any thermocouple is, however, greatly influenced by the effectiveness of its sheath. If metallic vapours or other volatile substances are able to diffuse through the sheath, rapid attack of the wires can ensue followed by a drift from calibrated values. In such cases the wires eventually become embrittled and mechanical failure occurs. Fortunately modern sheathing techniques are such that the incidence of failure is low, and noble metal couples can be used in all normal industrial atmospheres up to 1800 C or above.

There are occasions where standard ceramic sheaths are for one or more reasons unsuitable. The limitations of this type of sheath include its rigidity, the high thermal mass resulting in long response times, and the low resistance to thermal and mechanical shock.

In answer to the growing demand for a more flexible construction Johnson Matthey have recently introduced a metal-sheathed, mineral-insulated assembly known as the "*Metal-Clad Couple*". This type of assembly, illustrated below, consists essentially of a flexible metallic sheath containing the two thermocouple wires separated from each other and from the sheath by a high-grade refractory oxide. It is available in two standard sizes, 0.063 inch and 0.125 inch total outside diameters. The sheath may consist of 10 per cent rhodium-platinum, of 10 per cent rhodium-platinum joined at a specified point to a cheaper base metal, or completely of base metal. The base metals may be either pure nickel or stainless steel.

This photograph of the two standard sizes of the Johnson Matthey metal-sheathed mineral-insulated thermocouple shows both the flexibility of assembly and the special end cap provided for the cold junction.

The Platinum Metals

The above article in the October issue of *Platinum Metals Review* is typical of those published quarterly to keep metallurgists and engineers abreast of developments in the applications of the platinum metals in industry.

Platinum Metals Review is free on request. May we add your name to our mailing list?

Also in the October Issue:

Platinum Catalysts in Ammonia Oxidation · A New Hydrogen Purification Process · The Hydrides of Palladium and Palladium Alloys Thermal Expansion of Rhodium-Platinum Alloys · High Temperature Brazing of Heat-Resisting Materials · Second International Congress on Catalysis · Sensitive Elements for Leak Detection · The Platinum Metals in the Periodic System · Improved Stainless Steel Reactor Material

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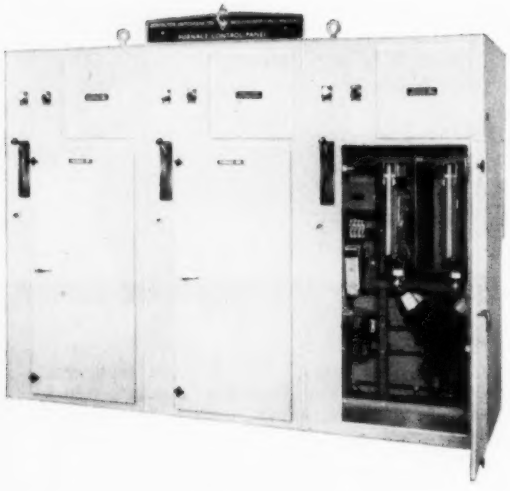

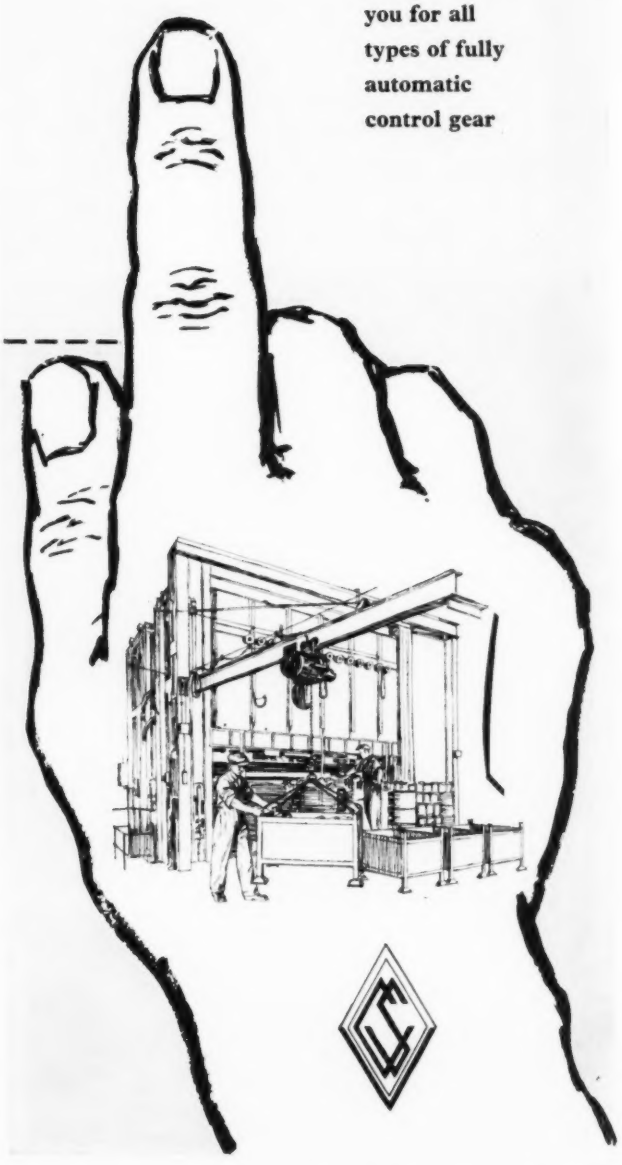

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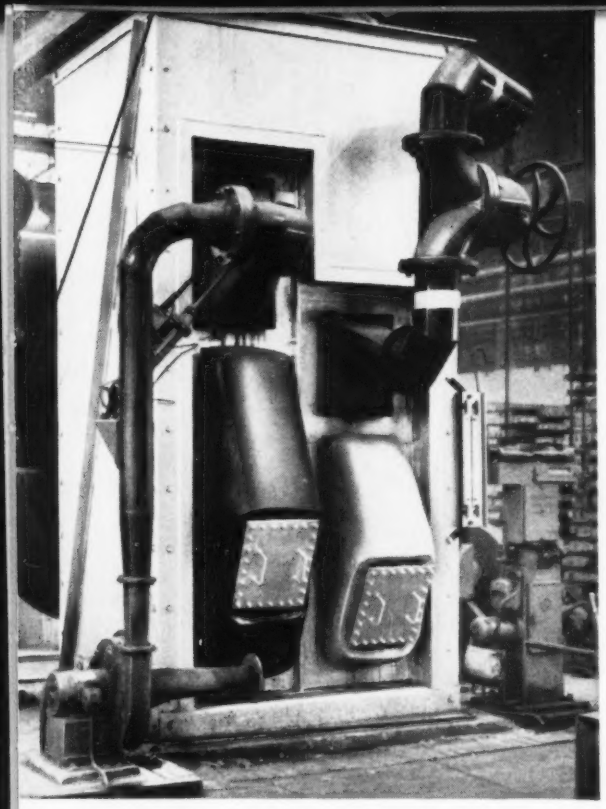

The Combined Newton Needle Air and Fuel Gas Recuperators shown above are installed on the Sterling Billet Heating Furnace at Messrs. Hadfields & Company Ltd, Sheffield, and incorporate this latest development in high pressure flexible-end connection.

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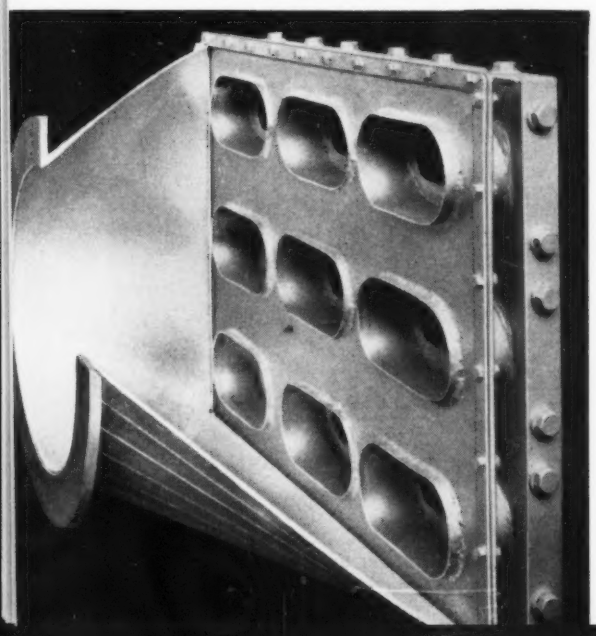
Our portable demonstration model. The oval shape tubular steel inserts are cast into the end-supporting flanges as an integral part of each heat-resisting cast-iron heat exchanger element. The steel inserts are welded into a thin steel diaphragm plate to which are connected the air and fuel gas inlet and outlet ducts, a completely gas tight joint is then ensured.



The latest introduction by Newton Chambers of the flexible-end (D.B. type) connections for high pressure air and fuel gas recuperators are now available and can be demonstrated. This type of construction successfully accommodates thermal extensions within recuperators when operated at temperatures of up to 1,050°C. on the exhaust furnace gas side, and up to 650°C. on the combustion air and fuel gas side.

We would welcome the opportunity to show you over installations now at work, and to discuss your recuperator problems with you.

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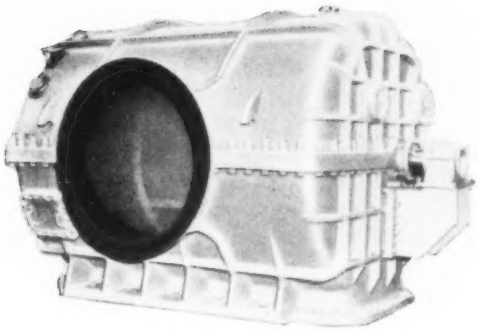
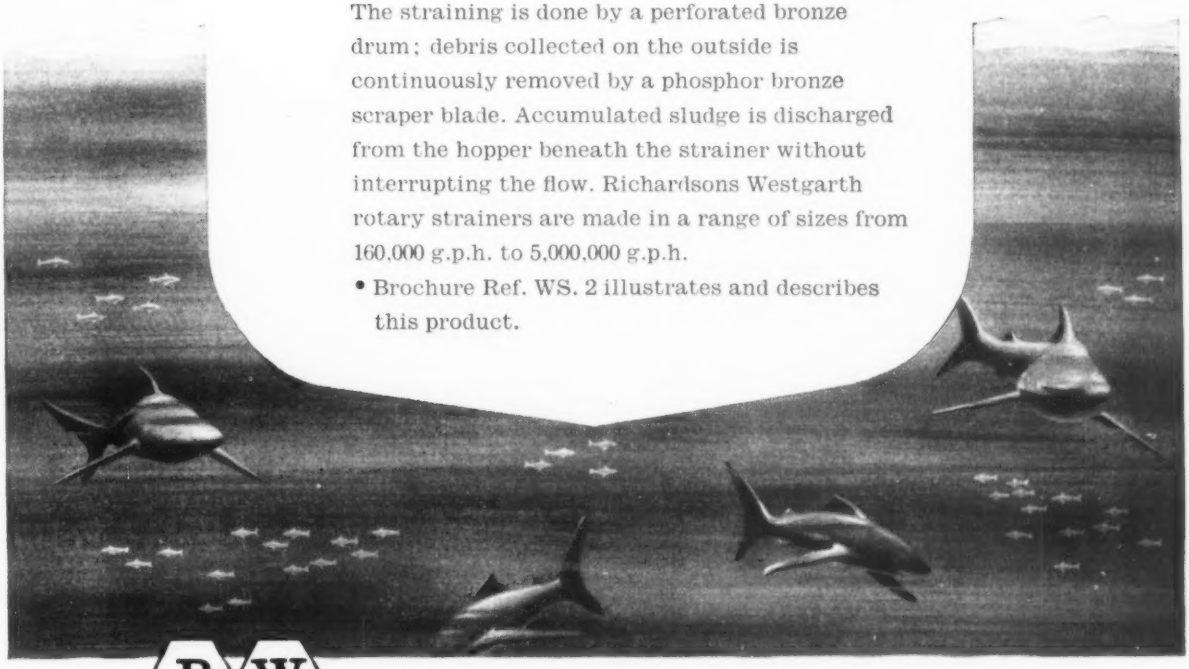


Enough water to float the 'Queen Mary'

Six Richardsons Westgarth 'Deptford' rotary water strainers strain the condenser cooling water at the Aberthaw Power Station, and are capable of handling 20,000,000 gallons in forty minutes—enough water to float the 'Queen Mary'. The straining is done by a perforated bronze drum; debris collected on the outside is continuously removed by a phosphor bronze scraper blade. Accumulated sludge is discharged from the hopper beneath the strainer without interrupting the flow. Richardsons Westgarth rotary strainers are made in a range of sizes from 160,000 g.p.h. to 5,000,000 g.p.h.

- Brochure Ref. WS. 2 illustrates and describes this product.



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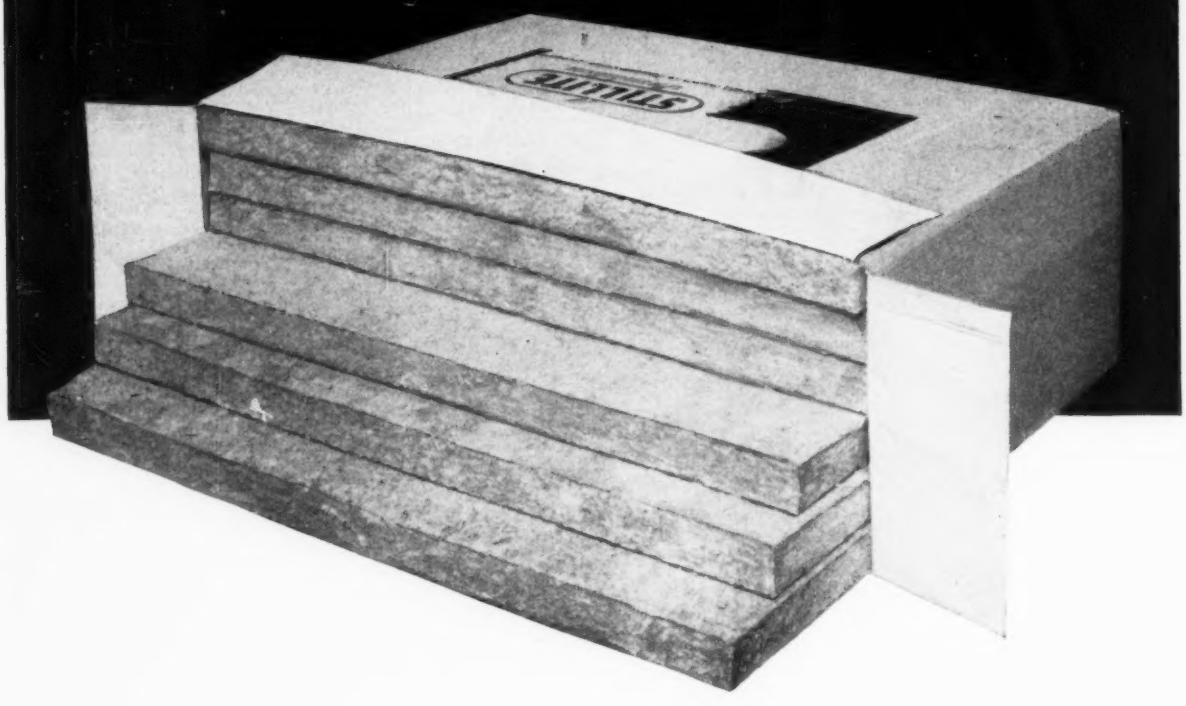

The furnace industry is well acquainted with THERBLOC★ for insulation up to 1500°F. Where lower temperatures are involved however, for example, core stoves and paint booths, consider *S.R.10 Mineral Wool slabs*. An inexpensive, yet valuable material not only for maintaining temperatures and reducing fuel bills but also to make working conditions more acceptable to operators.

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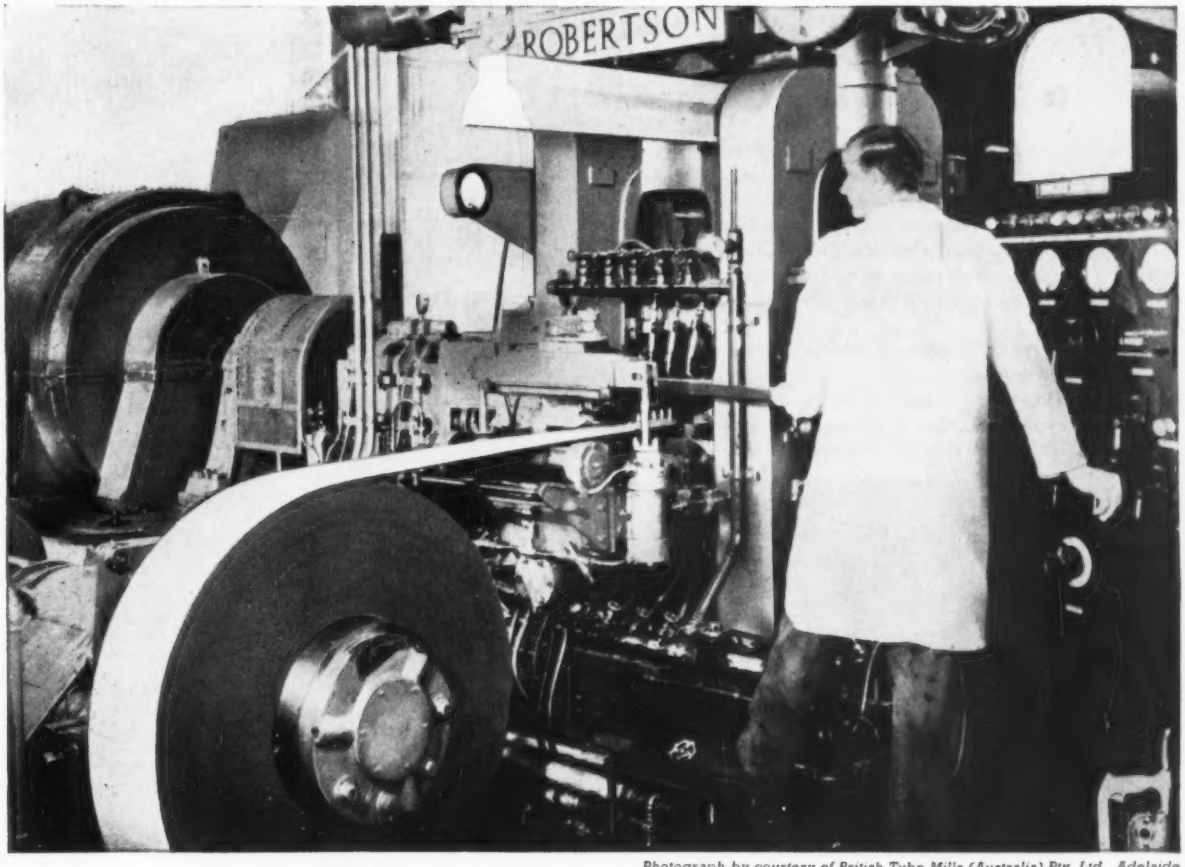

Photograph by courtesy of British Tube Mills (Australia) Pty. Ltd., Adelaide

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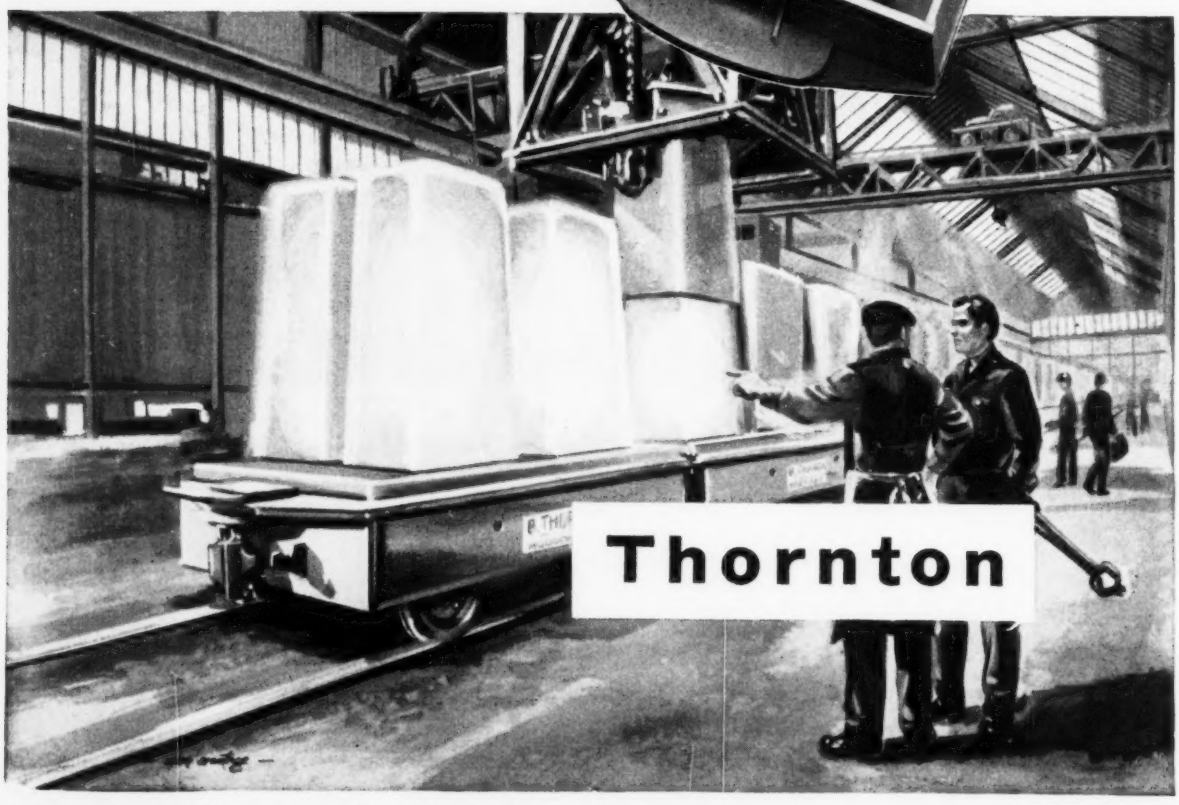

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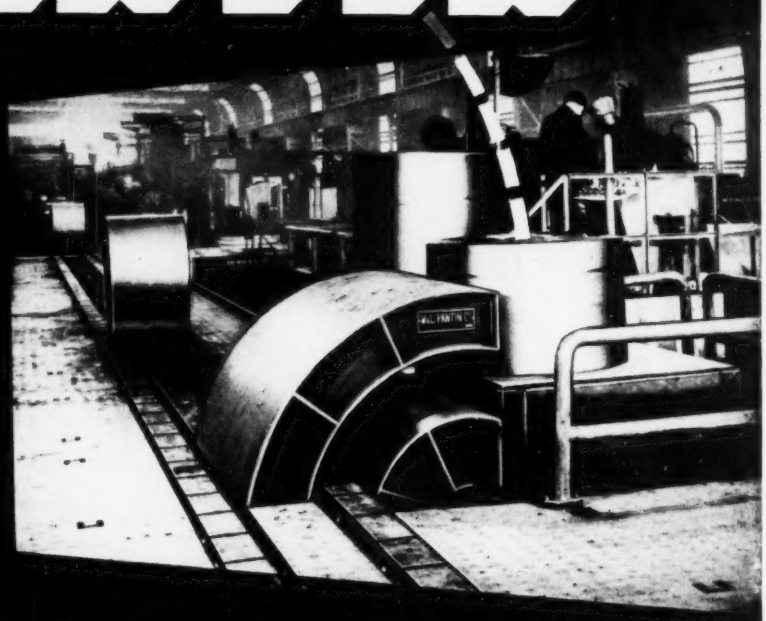
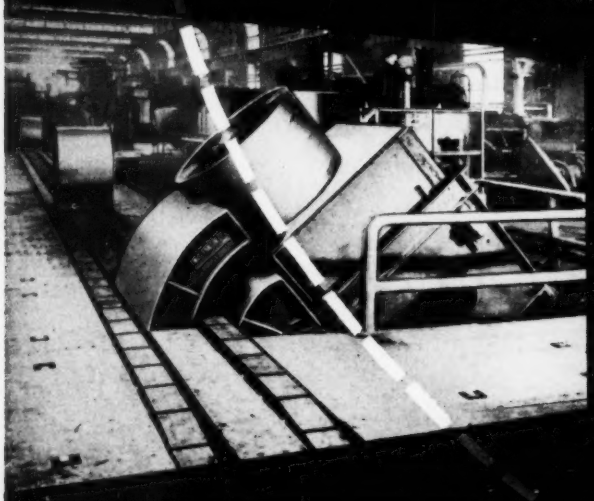
PANTIN

heavy–duty handling systems



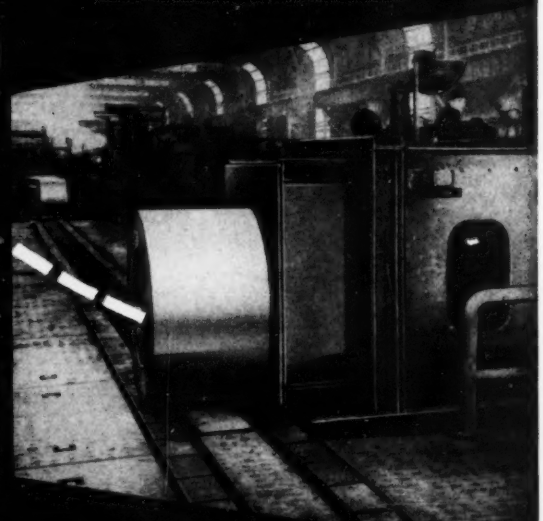


Pantin design and manufacture heavy duty mechanical handling plant for the Iron and Steel Industry.

This 'Upender', for example, was made to simplify and expedite the handling of coiled steel. With the utmost ease it takes coils up to 15 tons (max. dimensions 6' diam. × 6' wide) and lays them on a Pantin Pallet Conveyor for movement to the next station.

Pantin Handling Equipment covers every requirement, including upending and down-ending, tilting, hoisting and conveying of coils and sheets.

We are always pleased to discuss, advise and co-operate on the design of handling systems and shall be glad to send you details of Pantin Conveyors and Handling Equipment. Please write for illustrated brochure.



W & C PANTIN LTD CENTRE DRIVE EPPING ESSEX *Telephone EPPING 2271-4*

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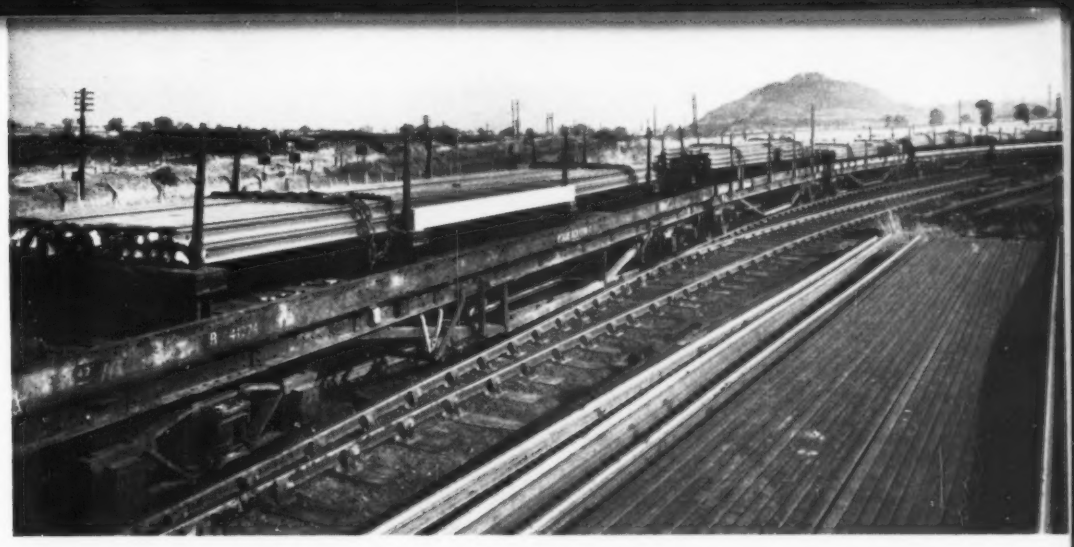


Two train loads of rails and switches leaving Summerson's Spennymoor Works.

SUMMERSON 'Designing' wins big Thailand contract for rails and switches

In the face of keen world wide competition Summersons obtained a contract from the State Railways of Thailand comprising 115 turnouts angle 1 in 10, complete with over-riding switches and cast manganese vee pieces, also seven diamond fixed crossings, angle 1 in 10, including two acute crossings with cast steel vees and two obtuse crossings. Ancillary equipment was also supplied.
Good designing was a deciding factor, and Summersons 120 years of experience of designing, manufacturing and laying railway track stood them in good stead. *Write for a copy of Summersons Book of Railway Sidings*

THOMAS SUMMERSON & SONS, LTD., MOWDEN HALL, DARLINGTON TELEPHONE DARLINGTON 5226

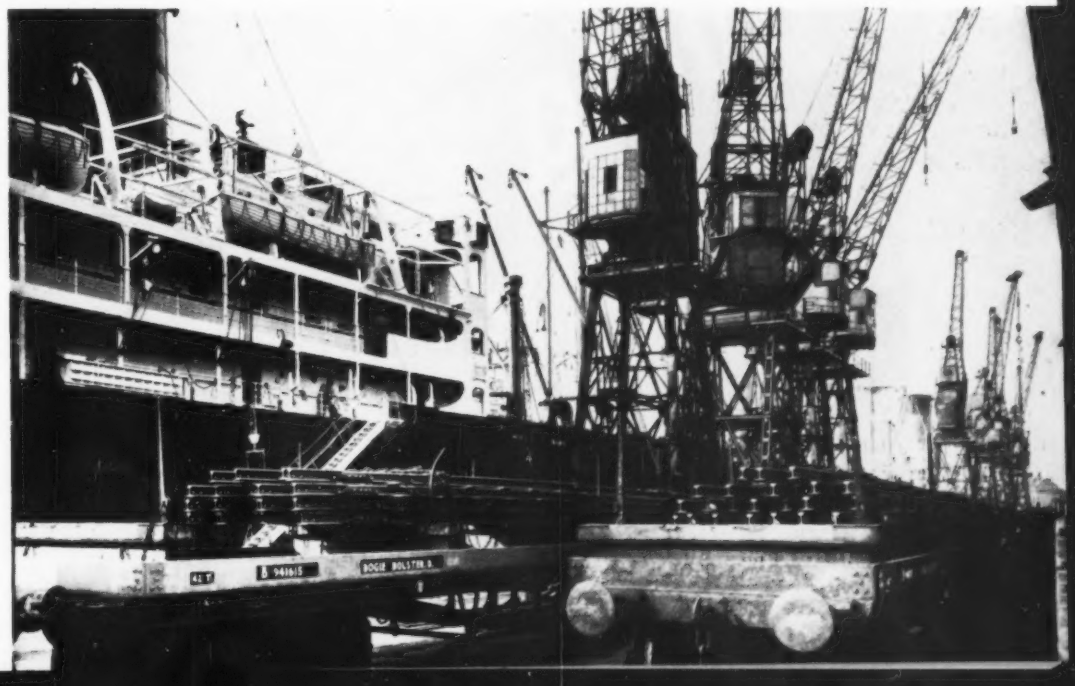
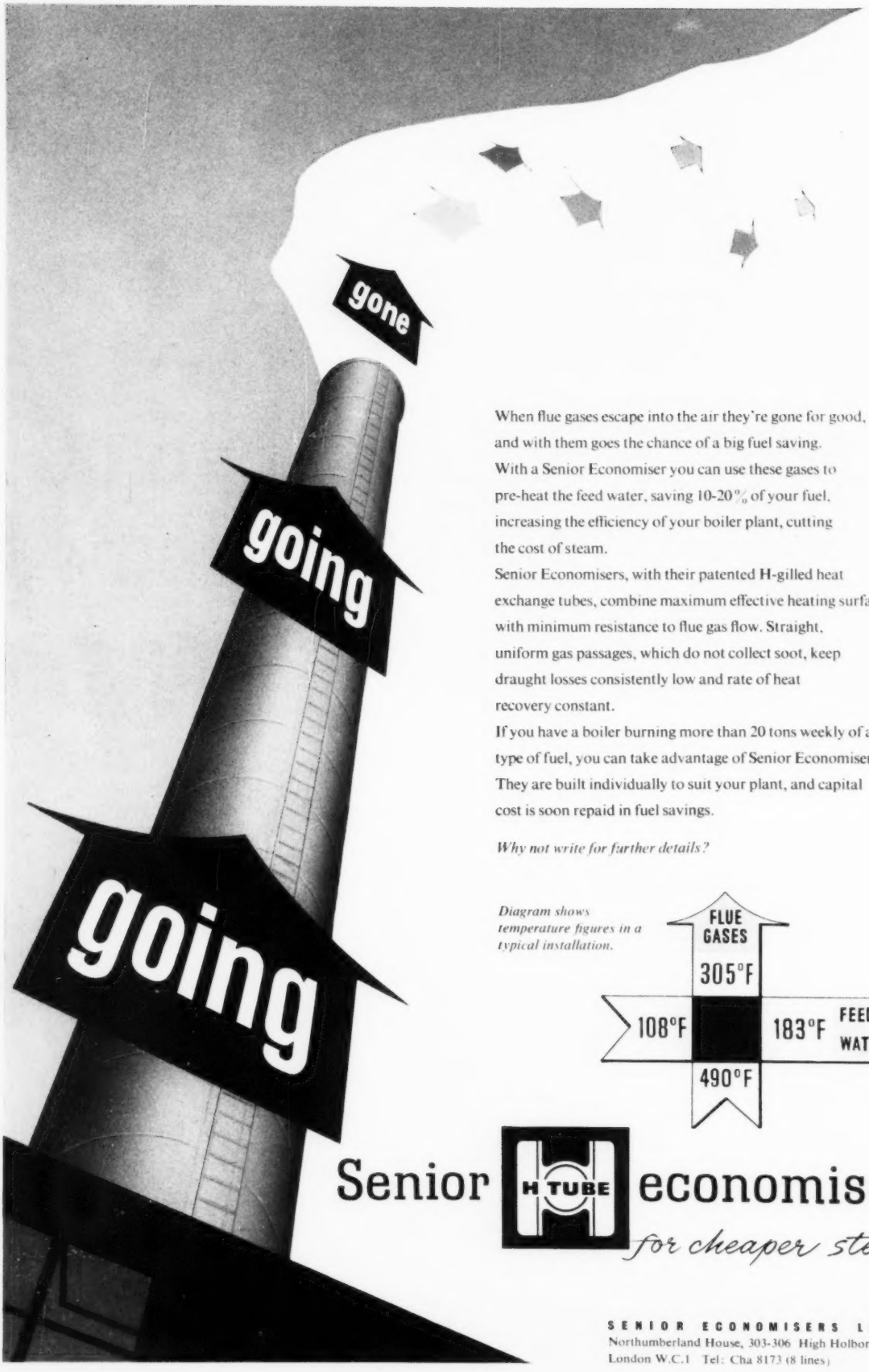


Illustration shows part of two complete trains used to deliver.



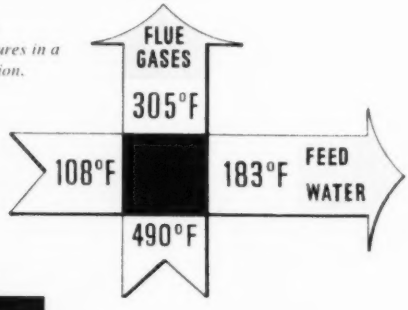
When flue gases escape into the air they're gone for good, and with them goes the chance of a big fuel saving. With a Senior Economiser you can use these gases to pre-heat the feed water, saving 10-20% of your fuel, increasing the efficiency of your boiler plant, cutting the cost of steam.

Senior Economisers, with their patented H-gilled heat exchange tubes, combine maximum effective heating surface with minimum resistance to flue gas flow. Straight, uniform gas passages, which do not collect soot, keep draught losses consistently low and rate of heat recovery constant.

If you have a boiler burning more than 20 tons weekly of any type of fuel, you can take advantage of Senior Economisers. They are built individually to suit your plant, and capital cost is soon repaid in fuel savings.

Why not write for further details?

Diagram shows temperature figures in a typical installation.



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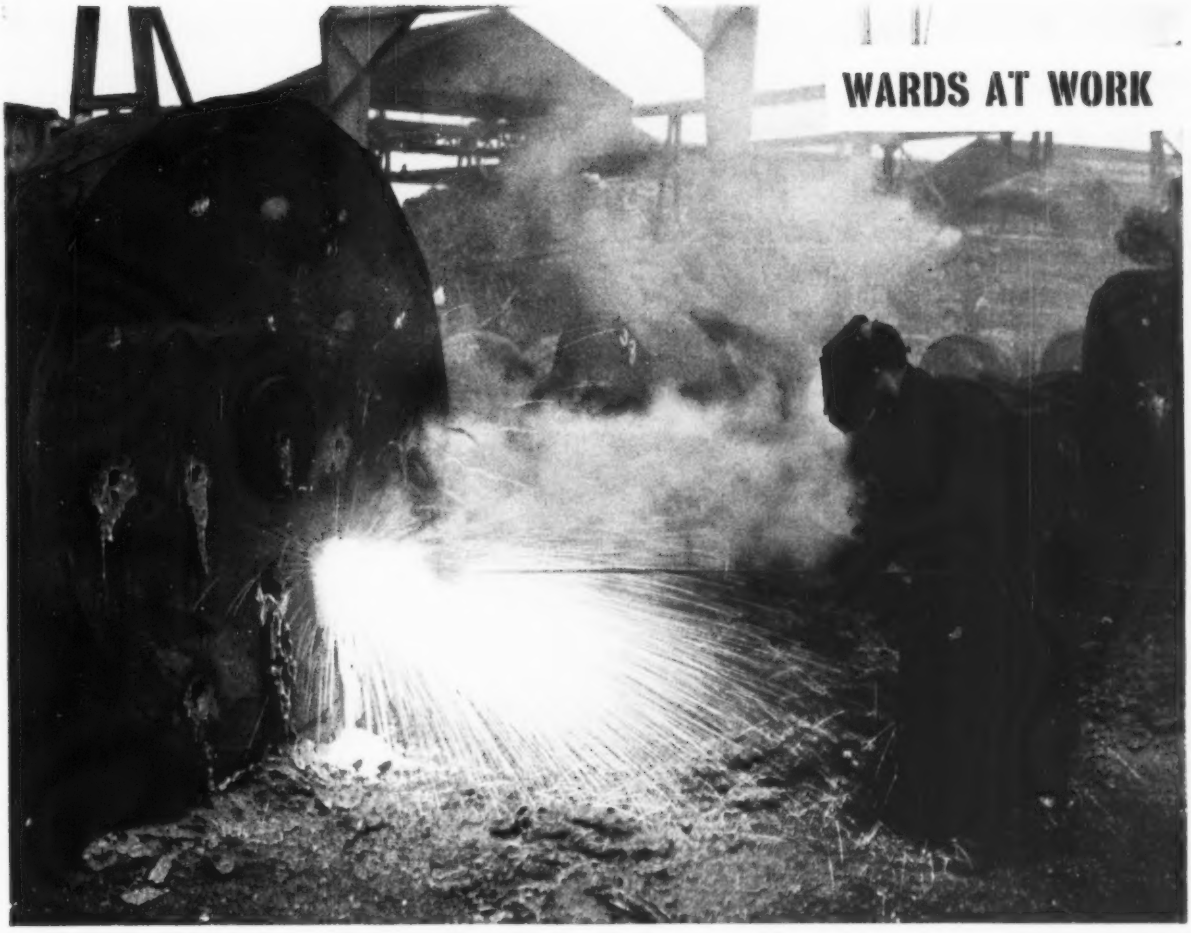

He turns base metal into gold!

No alchemist this, but a skilled scrapman in a Ward scrapyard. With his highly specialised experience, he can quickly prepare large masses of scrap for reduction to furnace sizes. Not only steel and iron, but all non-ferrous metals are handled too, both under strict metallurgical control. At scrapyards all over the country, equipped with the most modern plant, Wards handle thousands of tons of metal a day, and they are proud to be the leaders in this important industry.

Helping to feed the furnaces with carefully graded scrap is only one activity of the Ward Group of Companies whose products and services cover almost every branch of industry.

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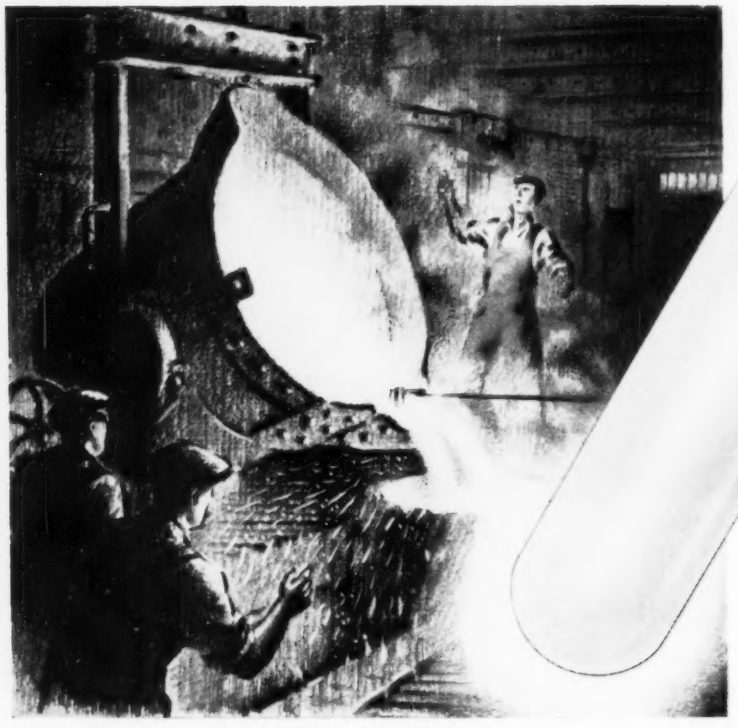

We also manufacture an extensive range of Vitreosil Laboratory Ware

VITREOSIL *DIPPING TUBES*

Casting temperatures are *critical!* Vitreosil, pure fused silica, sheaths used in the Quick Immersion Thermocouple Technique have obviated erratic judgement of casting temperatures in modern steelworks and foundries all over the world. A single dip into the molten metal gives the true temperature in seconds

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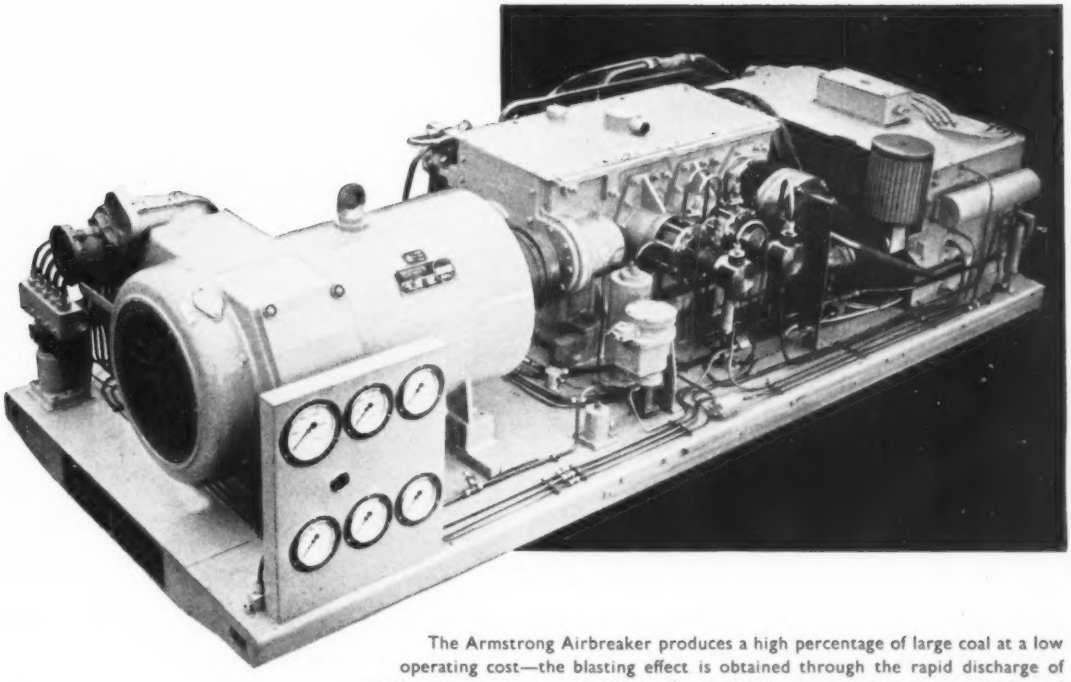
THE ARMSTRONG AIRBREAKER

The most modern method of coal blasting



The Armstrong Airbreaker produces a high percentage of large coal at a low operating cost—the blasting effect is obtained through the rapid discharge of high pressure air into the back of a drill hole. It entirely removes the hazard of firedamp ignition. It may be installed either on the surface or underground.

This is an example of the special-purpose machinery which can be built to customer's specifications or designed by our own staff. Our production facilities—a combination of modern, well-equipped shops and a highly trained staff of craftsmen and technicians—enable us to produce high precision work to any dimensions.

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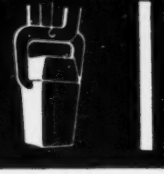

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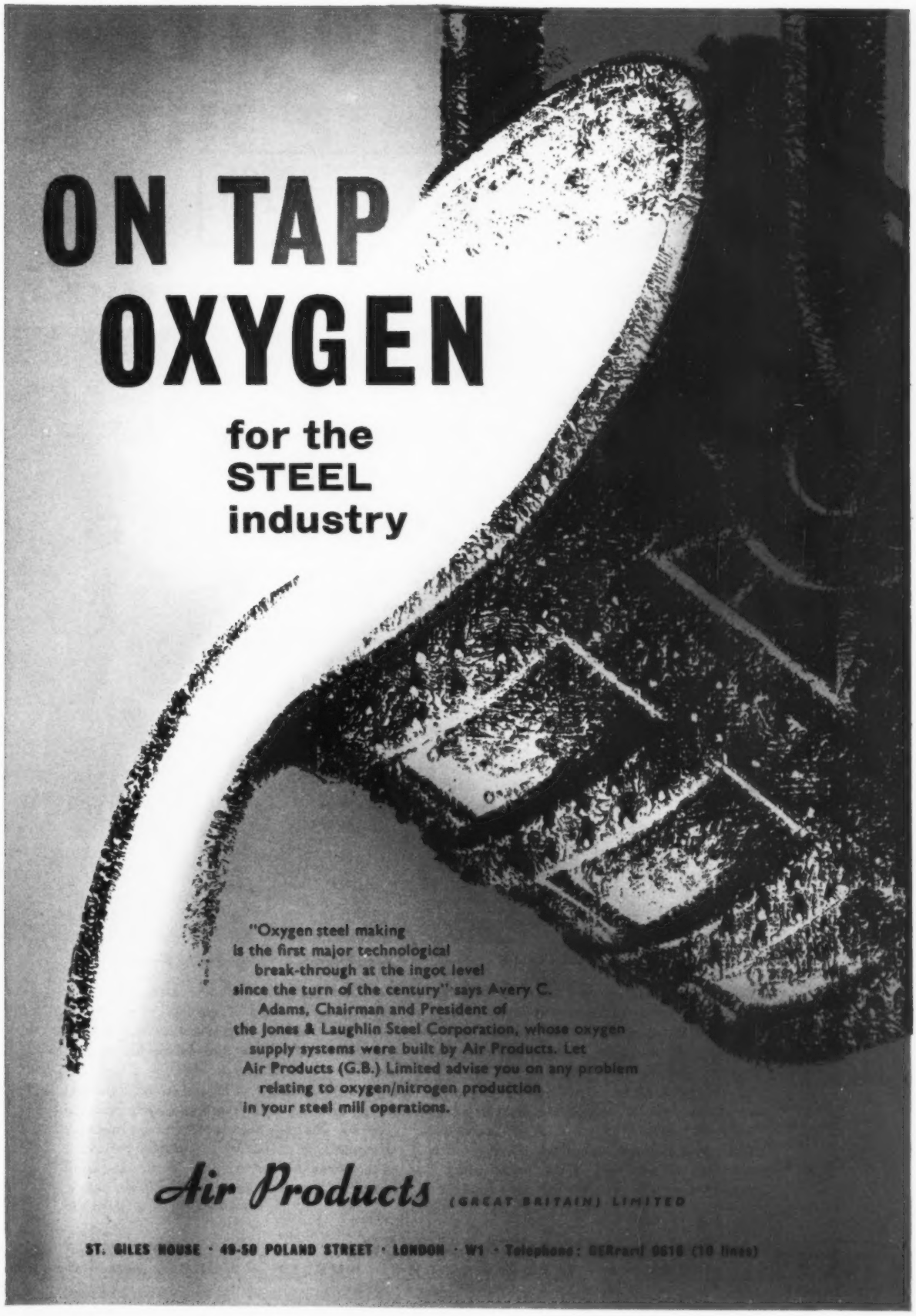

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"Oxygen steel making is the first major technological break-through at the ingot level since the turn of the century" says Avery C. Adams, Chairman and President of the Jones & Laughlin Steel Corporation, whose oxygen supply systems were built by Air Products. Let Air Products (G.B.) Limited advise you on any problem relating to oxygen/nitrogen production in your steel mill operations.

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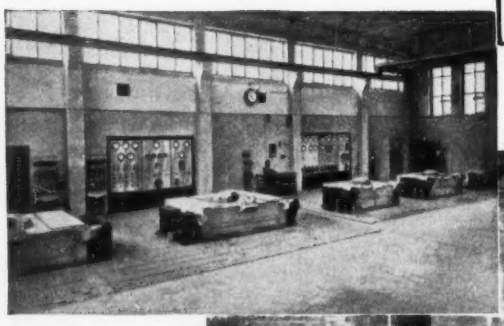
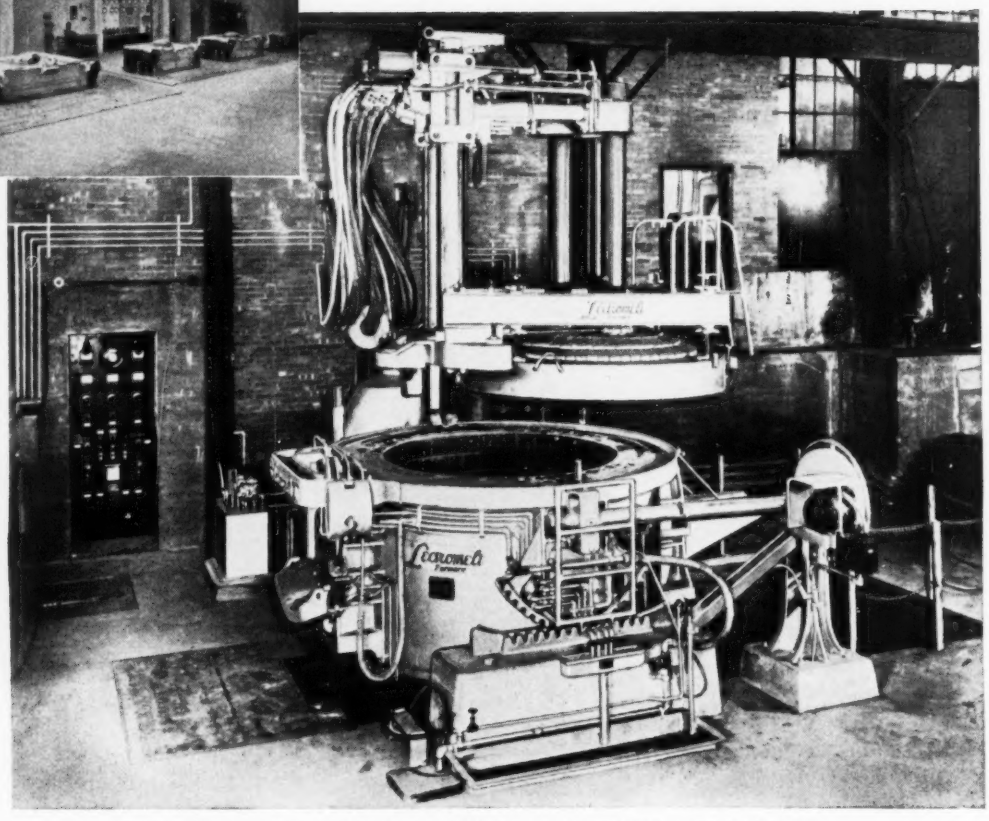
Lectromelt



Demag high-frequency induction furnace installation at a steel making plant, incorporating two 1 ton capacity furnaces, two 660 lb. capacity furnaces, and one 110 lb. capacity furnace.



A 3 ton capacity Lectromelt arc furnace of 9' 0" diameter shown with roof swung ready for charging.

High Speed and High Output are the key features in the medium and smaller range of furnaces offered by G.W.B. Furnaces Ltd. Many years are behind both the Coreless and Arc Furnaces of Demag and Lectromelt designs.

Daily, electric furnaces are finding wider and wider applications, and the coreless induction (crucible) type is no exception as it is an ideal medium for melting steel and iron, and all other metals. It is particularly advantageous in steel works where a charge of scrap of known analysis is melted and is an installation that pays for itself in a very short time. The proven economies of operation of electric arc furnaces offered by G.W.B. have earned an enviable reputation, and a few of their outstanding features are:—

Separately mounted roof lift and swing mechanism for top charging; Four point roof suspension of the roof ring; Electrode holders of the power operated, spring-held, air release type; High speed movement of the electrodes; Offset rocker centres to return furnace from extreme tilt in event of power failure.

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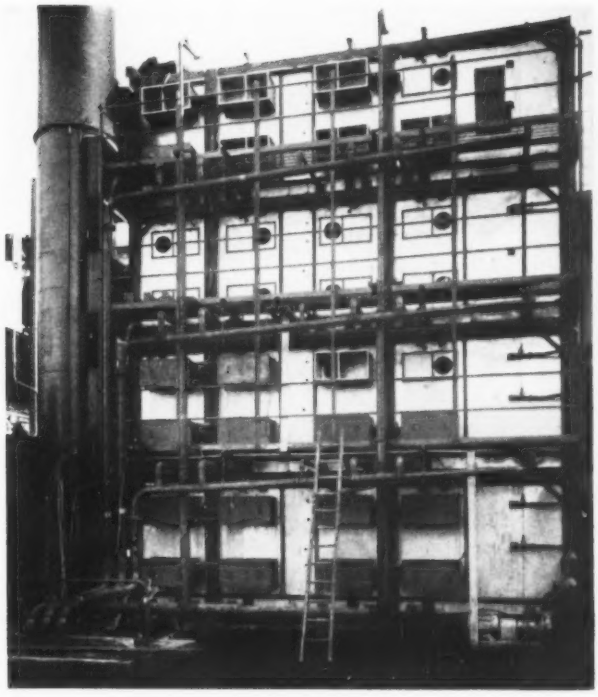

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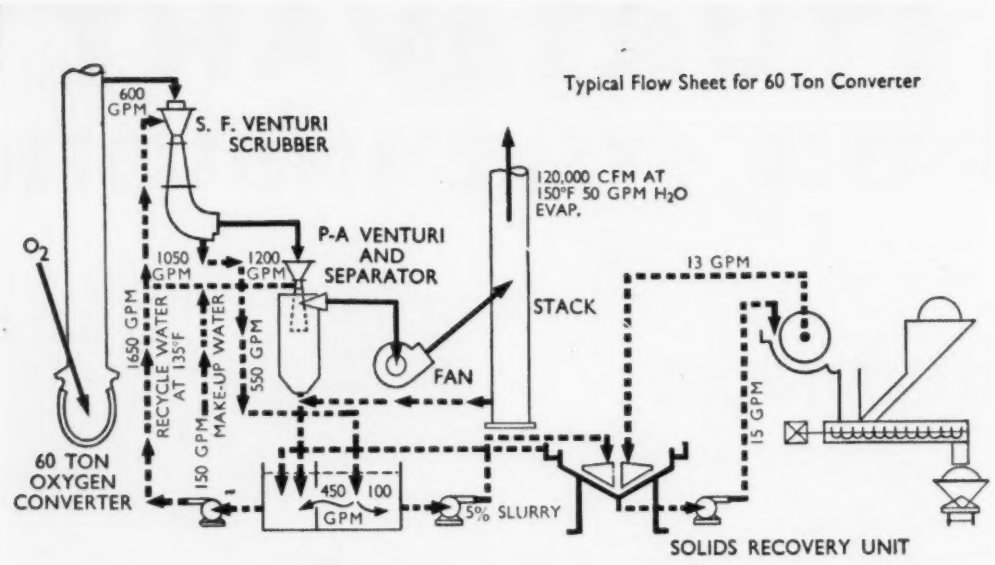
AUSTRALIA: STURTEVANT ENGINEERING CO. (AUSTRALASIA) LTD., 400 SUSSEX STREET, SYDNEY, N.S.W.



six converter installations prove

The recent installation of Chemico Venturi Gas Scrubbers at a major steel plant in Canada marks the sixth time Venturi Gas Scrubbers have been used to prevent an extremely undesirable source of air pollution—Iron Oxide Dust. Chemico Venturi Scrubbers maintain leadership in the world's steel industries because they offer wet scrubbing which allows non-explosive collection, efficiencies above 99% and extremely low maintenance. In addition no critical controls are required to maintain efficiency and the handling of dust is simplified by recovery in a dry form. Chemico Gas Scrubbers are ideally suited for Open Hearth Furnaces, Cupolas, Scarfing operations, Sintering operations, and Electric Furnaces. For further information and a copy of a brochure giving full particulars, contact the Chemico Gas Scrubber Division:

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Taking heavy end-thrust

Photo by courtesy of Davy and United Engineering Company Limited.

Fitting a two-row Timken steep-angle bearing on the screw-down gear of a new 144-inch 4-high mill.

Timken bearings—in addition to their outstanding service on roll necks—are used for mill-drive and pinion stands, for journal and thrust bearings for reels, for roller table line shafts, mill table rollers, breaker blocks and many other rolling mill applications.

Timken bearings, with their finest quality case-hardening nickel-alloy steel and carefully controlled heat treatment, have a hard wear-resisting surface of great durability and a resilient shock resistant toughened core.

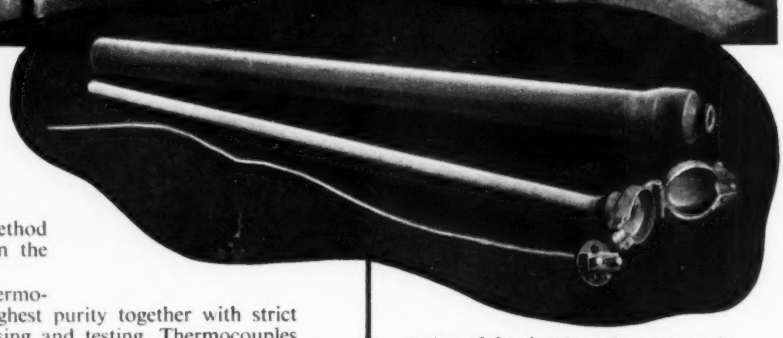
British Timken, Duston, Northampton, Division of The Timken Roller Bearing Company. Timken bearings manufactured in England, Australia, Brazil, Canada, France and U.S.A.

TIMKEN®

REGISTERED TRADE-MARK

tapered roller bearings

Accurate temperature control



A view of the electric soaking pits at the works of The Consett Iron Company, which are controlled by means of 95% platinum—5% rhodium versus 80% platinum—20% rhodium thermocouples.

The measurement and control of high temperatures is of fundamental importance in the manufacture of high quality steels, and platinum and platinum-rhodium alloy thermocouples have become the accepted method of exercising such control at all stages in the making of fine steels.

The manufacture of precious metal thermocouples demands raw materials of the highest purity together with strict scientific control at every stage of processing and testing. Thermocouples manufactured by the Baker Platinum Division of Engelhard Industries Ltd., have been proved to be of the highest possible quality, conforming in every respect to the relevant requirements of B.S.1826:1952 and B.S.1041:1943.

Continued research by Engelhard Industries in the field of high temperature pyrometry has resulted in two recent developments:

THE INTEGRAL-SHEATH THERMOCOUPLE, which has a diameter in the order of $\frac{1}{16}$ in. and combines compactness, flexibility and resistance to thermal shock to an extent unattainable with conventional sheathed assemblies.

'FIBRO' THERMOELEMENT PLATINUM, which maintains high strength and ductility after long periods at high temperatures whilst retaining all the thermoelectric attributes of normal thermoelement quality platinum.

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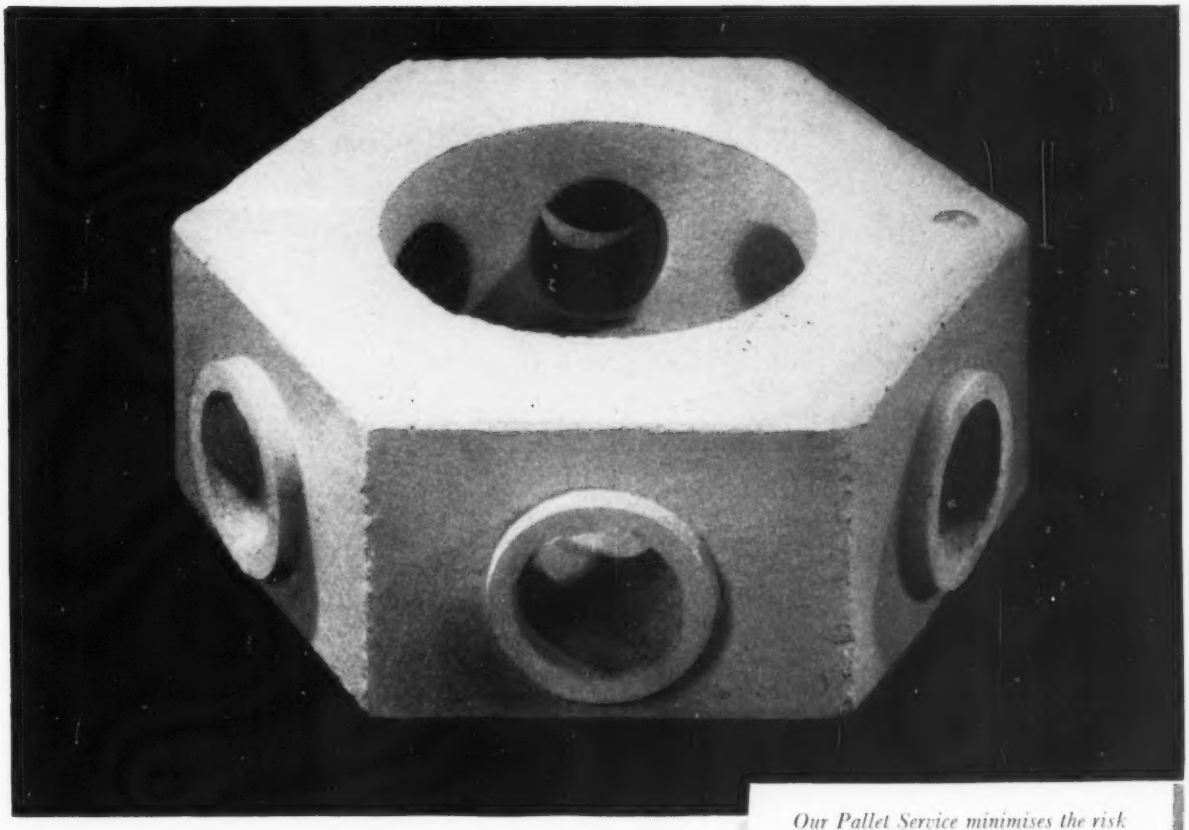

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These attributes stem from years of specialisation in the casting pit refractory field, in which Wraggs were pioneers. And they all add up to the solid reliability demanded by to-day's busiest steelmakers.

Our Pallet Service minimises the risk of damage in transit — saves time and trouble in handling. Particulars gladly sent on request.

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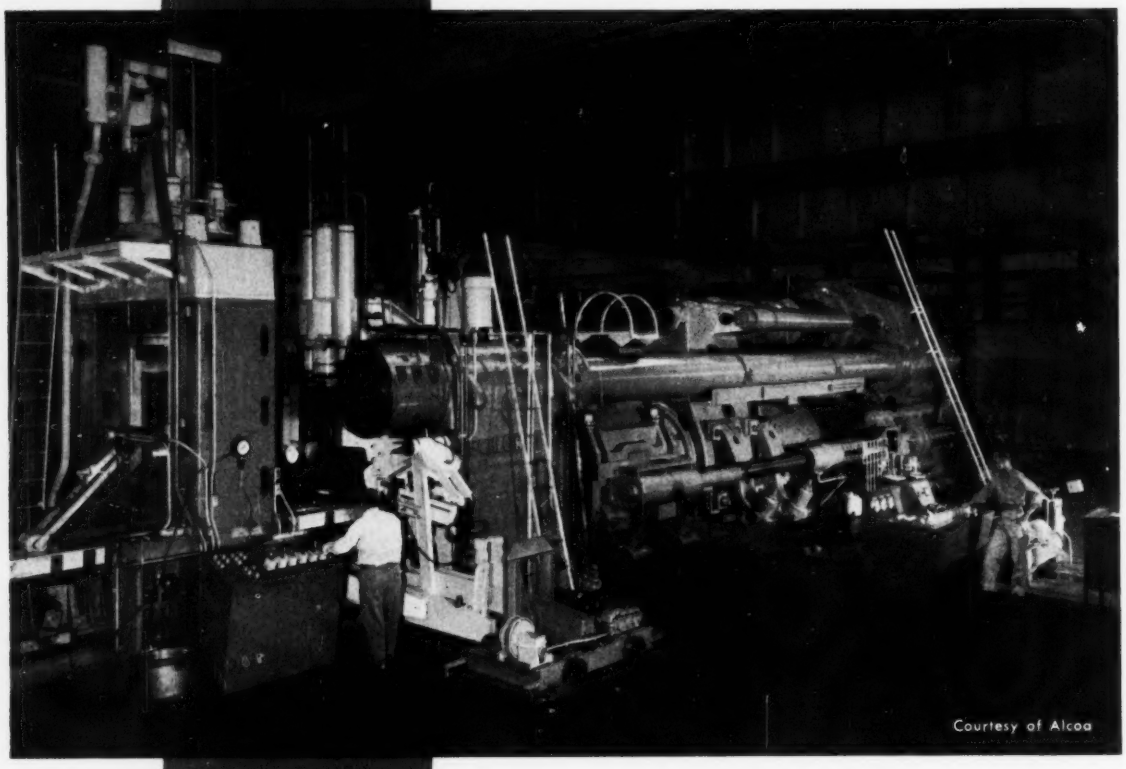

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Sales targets are difficult to achieve when production is hampered by obsolescent equipment. SCHLOEMANN is prepared to modernize your plant with highly efficient machinery, for either light or heavy work.

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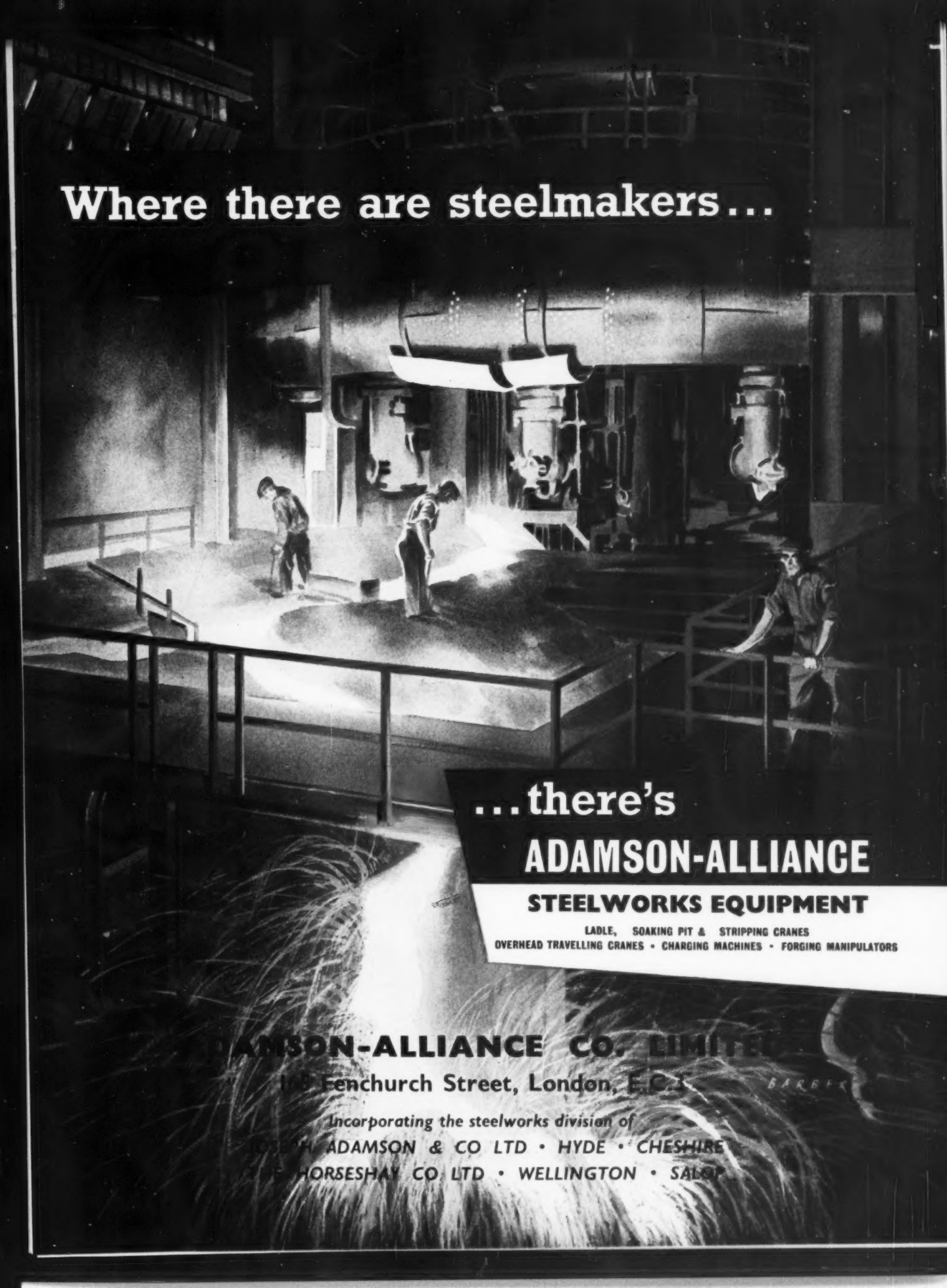
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FOR THE PRODUCTION OF LOW SULPHUR LIME FOR THE STEEL INDUSTRY

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Soaking Pits of all types.
Continuous Multi-zone Bloom and Slab-Re-heating Furnaces.
Continuous Bogie type Ingot and Slab Heating Furnaces.
Furnaces for Aluminium Melting, Coil Annealing and Slab Re-heating.
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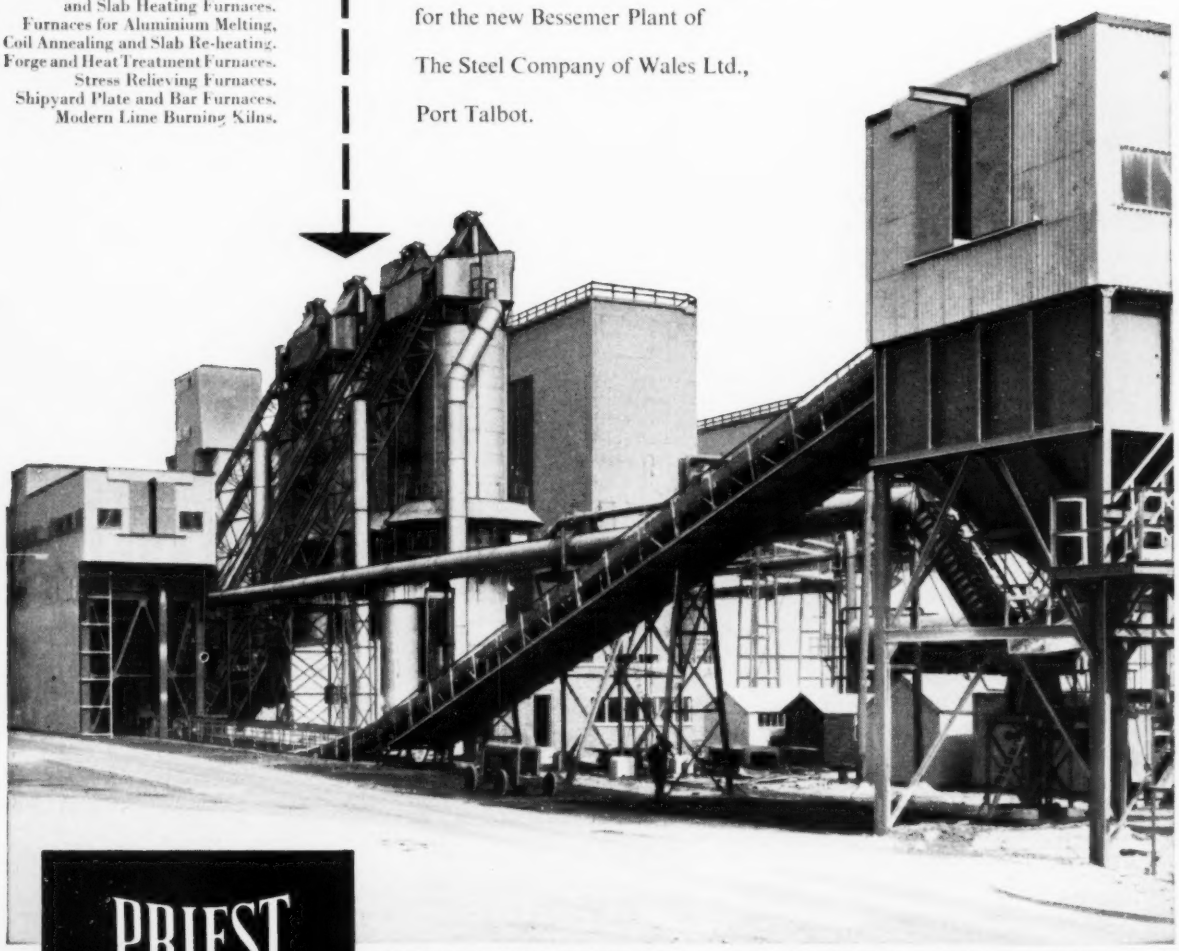
Modern Lime Burning Kilns.

The Plant illustrated includes 4 Mixed Gas Fired Kilns complete with Limestone and Lime Handling Equipment. Each Kiln produces 75 tons of lime per day for the new Bessemer Plant of The Steel Company of Wales Ltd., Port Talbot.



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The Barber, Engraving by A. Bosse, circa 1640.

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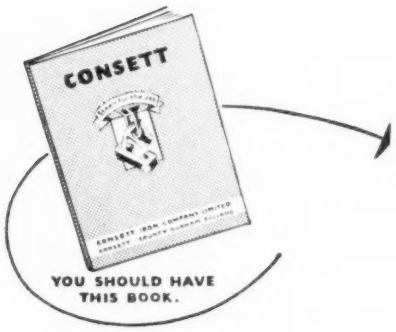
Every man to his own trade –
... and our trade is STEEL!



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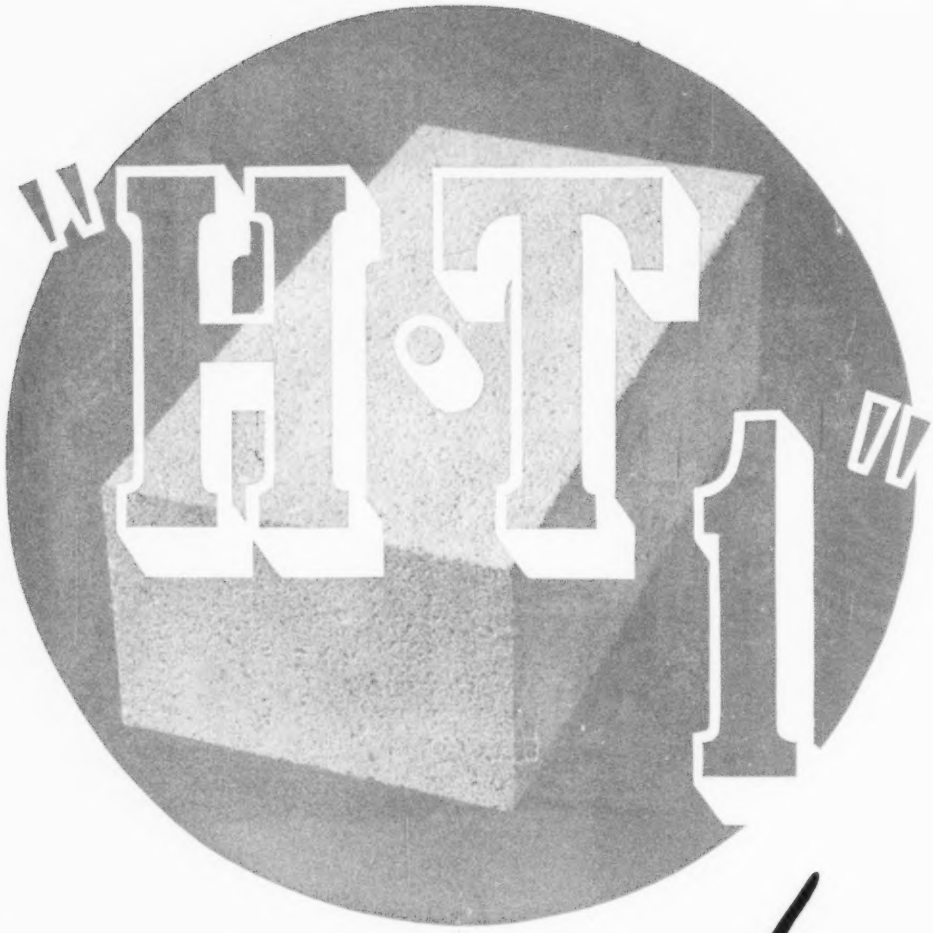

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From experience Gibbons "H.T 1" insulating refractory is the automatic choice of leading furnace manufacturers and users — its combination of low thermal conductivity with resistance to high temperatures has proved remarkably effective in minimising heat losses and raising furnace outputs. The Gibbons "H.T 1" is developed from more than 20 years' experience in the manufacture of insulating refractories and today an entirely new and original manufacturing technique enables us to offer material having unique physical properties at a price you can afford to pay.

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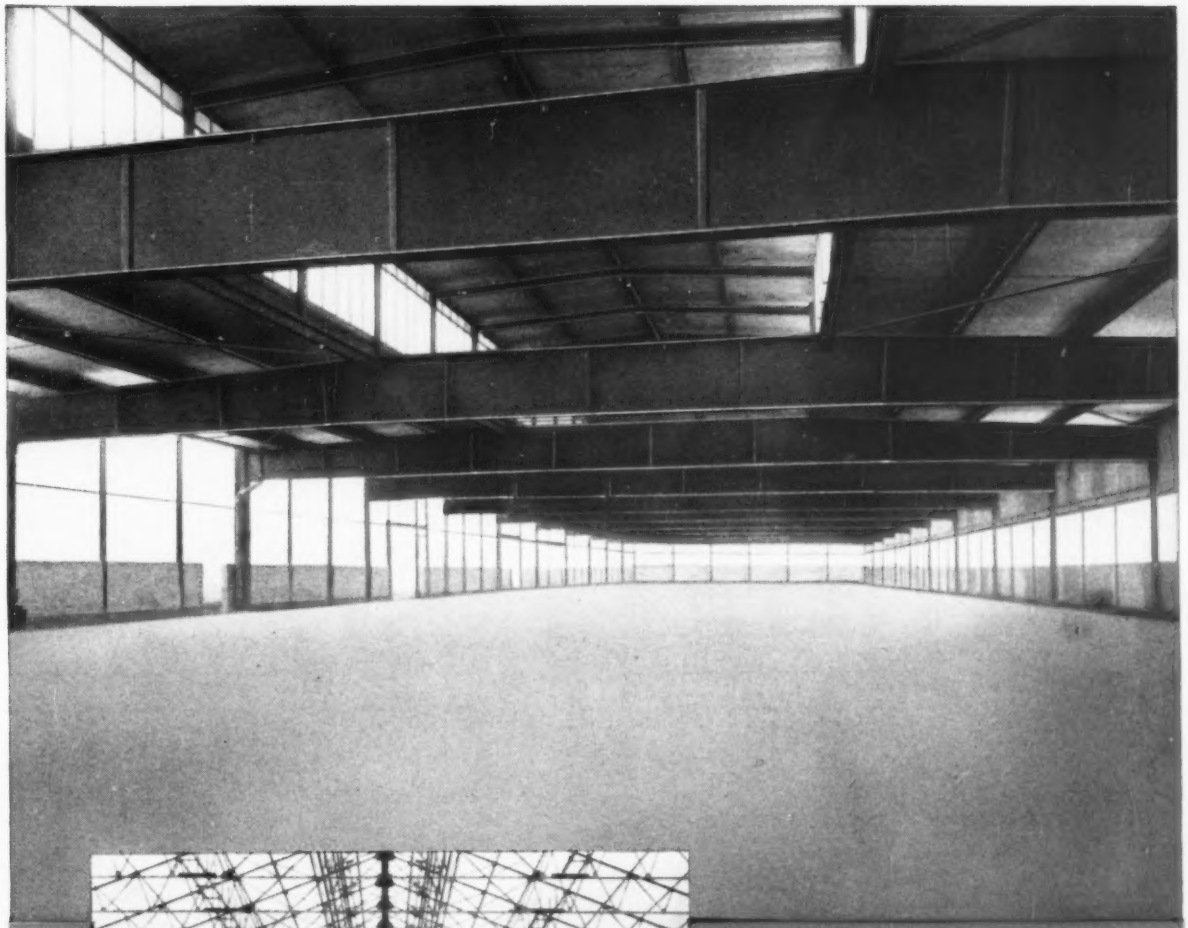
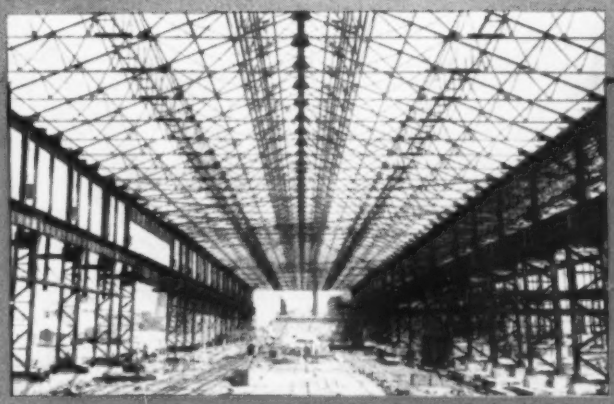


400′ × 100′ Production Shop for English Steel Corporation Ltd., Openshaw, Manchester.



Billet Mill at Durgapur Steelworks, India

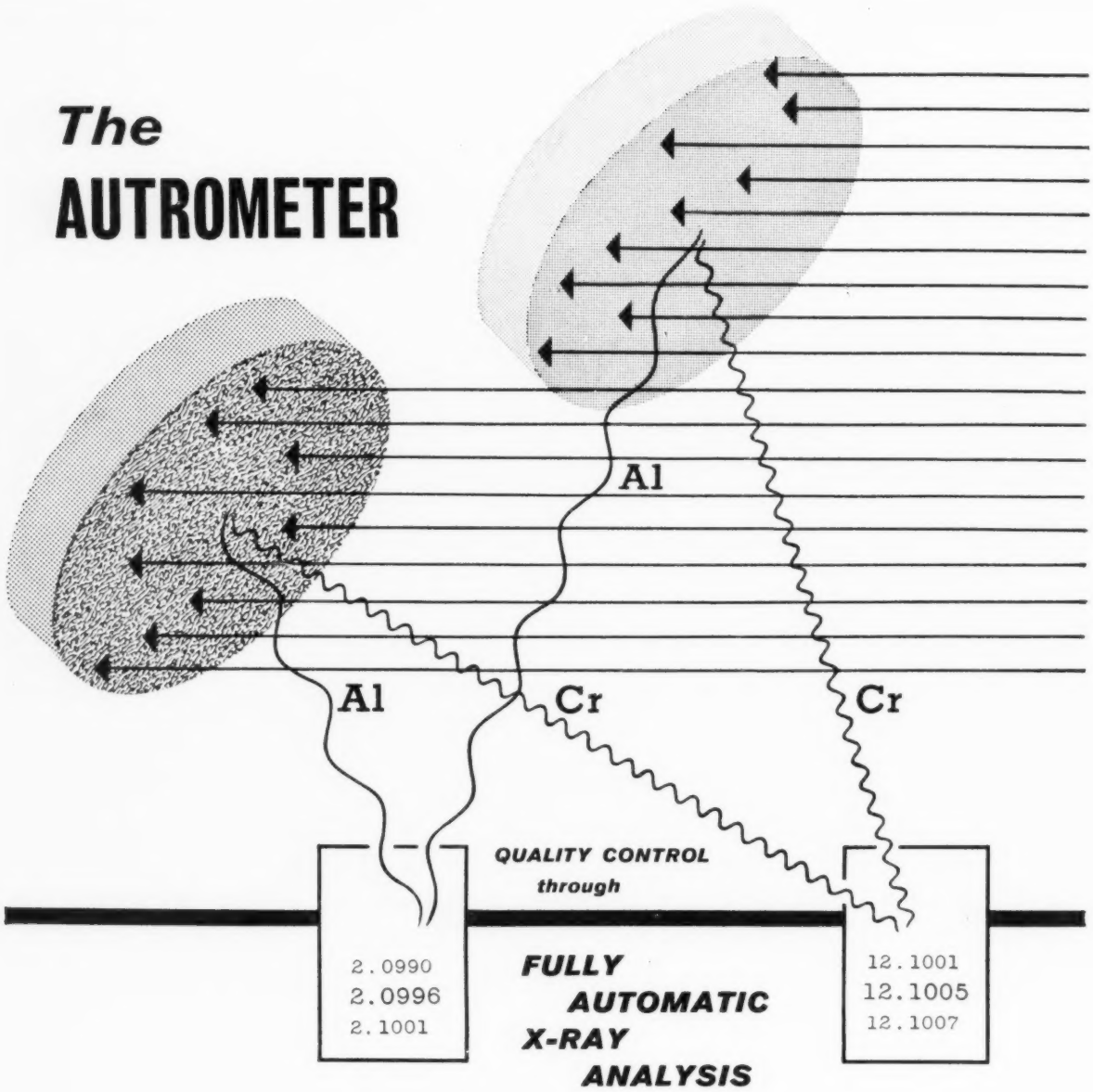
Steelwork for Industrial Buildings

Long and varied experience of the fabrication and erection of heavy structural steelwork contributes to the success with which ARROL handle widely differing contracts. These photographs illustrate this diversity of activities and reflect their high reputation throughout the world.

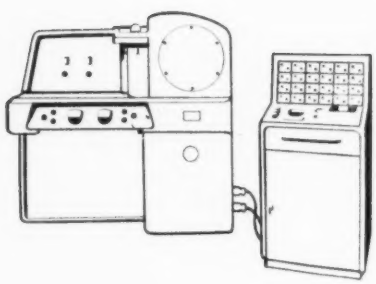
SIR WILLIAM ARROL & CO LTD GLASGOW

Arrol

The AUTROMETER



The more-than-modern instrument that brings the impersonal and reproducible precision of spectographic analysis to every branch of industry.



THE AUTROMETER

- Being precision-set, *needs only to be fed with samples.*
- Being fully automatic, can be operated by one unskilled attendant.
- Being free from human error, gives *absolutely consistent results.*
- Makes qualitative and quantitative analysis of *as many as 24 elements* in one sample.
- Uses a comparator system with single electronic chain.
- Provides by far the *speediest* method of elemental analysis by x-rays.
- Element range: Magnesium (12) to Californium (98).
- Is the ideal analytical tool for *high* consistency runs.

  And: the Autrometer has exceptionally rapid after-sales service.
- *A product of Philips Electronics and Pharmaceutical Industries Corp. U.S.A*

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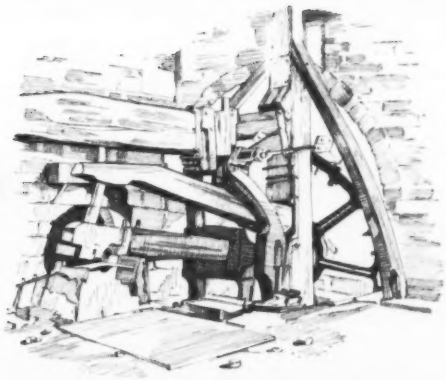
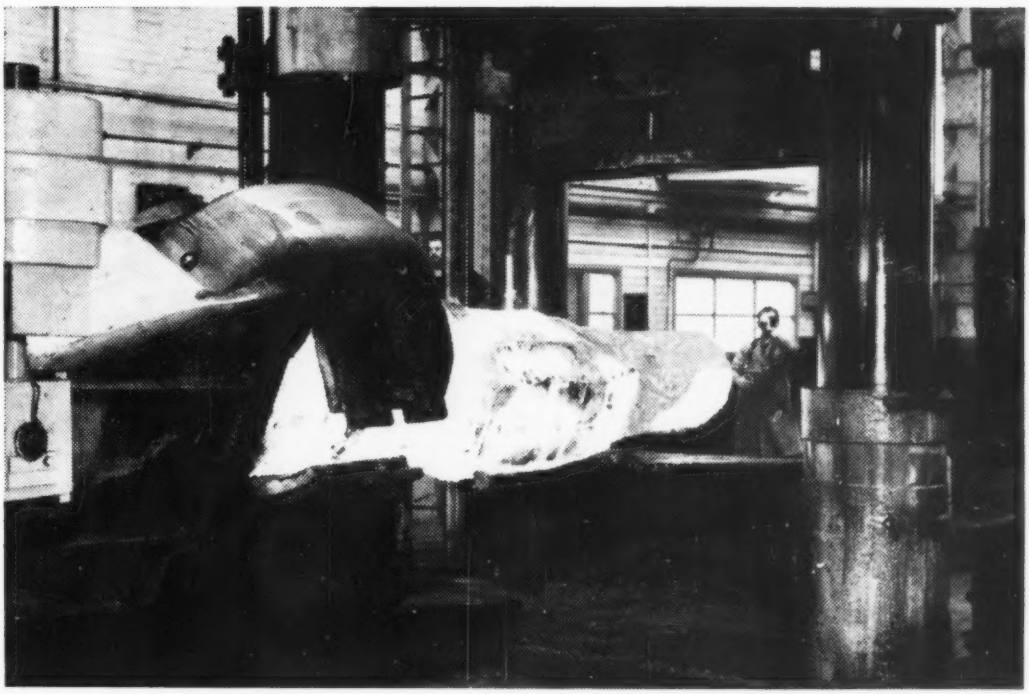
Instrument House, 207 King's Cross Road, London, W.C.1 TERminus 2877

(RCL0450)

Steel in Both the Sixties





By 1860, Firth Brown, leaders even in those days, were far advanced in the techniques of forging quite large masses of steel.

Now—one hundred years later—Firth Brown are still acknowledged leaders in the making of the largest special forgings for Power Station Rotor Shafts, Forged Steel Rolls, and large units for Power transmission and Ships' propulsion.

FIRTH BROWN

ALLOY STEELMAKERS · FORGEMASTERS · STEEL FOUNDERS · HEAVY ENGINEERS

THOS. FIRTH & JOHN BROWN LIMITED SHEFFIELD · ENGLAND

Modern carving in Ardington Parish Church of pigs feeding on acorns. Photograph by Ruth Meyler & F. C. Sillar

50 MILLION PIGS GO TO MARKET!

In the early days of the industrial revolution manufacturers frequently looked for familiar and easily recognisable descriptions of their products. To the countryman transplanted into industrial surroundings nothing was more familiar than a pig; a fact which is emphasised by carvings in scores of old churches depicting pigs suckling their litter, rooting for acorns and playing the bagpipes. (Apparently this last pastime was forsworn by pigs many years ago because of unpleasant associations between bagpipes and pigs bladders.) Consequently, when iron from Blast Furnaces was directed into long troughs and from there into short and narrow troughs placed at right angles, a resemblance to sows suckling their appendaged litter led to the description of 'pig iron'.

This series of advertisements illustrates some of the 'ecclesiastical' pigs and emphasises the 50,000,000 'special' pigs which Warner and Company have supplied to Iron Foundries producing High Duty Castings.

WARNER WARNER WARNER

"Pioneers of Refined Pig Iron"

KA

WARNER & CO. LTD., MIDDLESBROUGH

Specialist-designed **Refractories**

MULLOX Brand

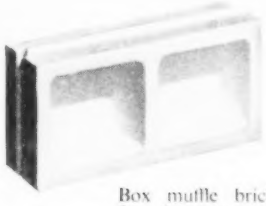
SILLIMANITE BRICKS AND SHAPES

'Mullox' bricks have been specially designed for all structures subjected to mechanical stress or thermal shock at high temperatures. By suitable kiln-firing treatment they acquire excellent spalling resistance and at extreme temperatures exhibit negligible volume changes.

All brands are characterised by a low amount of fluxing impurities, which is ensured by using Sillimanite bonded with varying amounts of pure Devon Ball Clay.

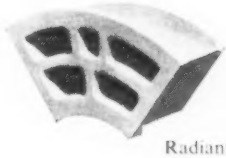
They withstand the corrosive action of most slags and are not attacked by either oxidising or reducing atmospheres.

All jointing should be carried out with 'Mullox' cement which has been developed specially for use with 'Mullox' bricks.

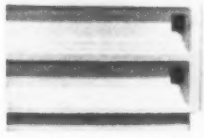


Box muffle bricks for heat-treatment furnaces.

Burner block



Radiant heater block.



Electrical resistor tile.

APPLICATIONS

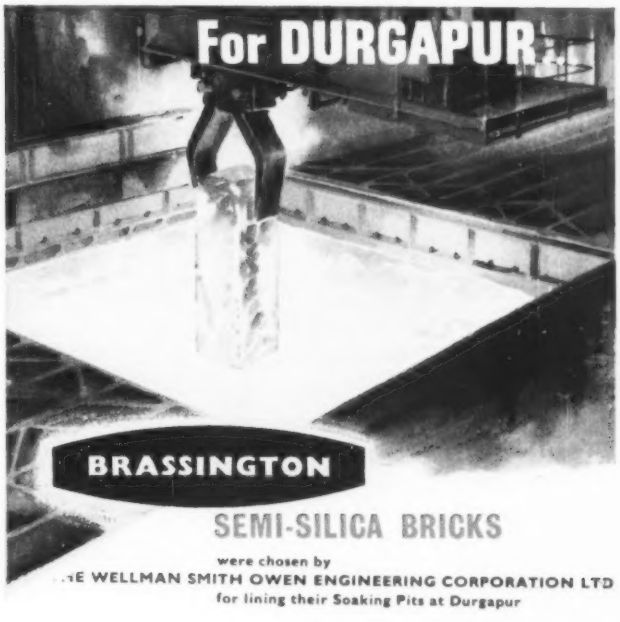
Combustion Chambers and fireboxes · Burner Blocks
Gas Port Blocks · Burner Baffles · Hearth Tiles · Sidewalls
Roofs · Hot repair Tiles

BRASSINGTON

SEMI-SILICA BRICKS SHAPES AND CEMENTS

The Swann Brassington semi-silica brick is prepared by blending specially hand picked sand from the Company's extensive deposits with a small amount of Devon Ball clay, thereby ensuring a consistent product with a minimum amount of impurity.

Semi-silica bricks are characterised by a considerably higher resistance to thermal shock than normal silica bricks, volume stability, and a tendency to glaze in service. When used in conjunction with Swann Brassington siliceous cement, the bricks and cement glaze together forming a monolithic structure. Failure due to joint erosion is therefore eliminated. The bricks have a high resistance to erosion by slag attack and to abrasion by dust-laden furnace gases.



★ *Full technical literature on request*

SWANN, RATCLIFFE & COMPANY (BRASSINGTON) LTD

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GIVE YOU AIR ON A FAMILIAR THEME

VISCO equipment is specially designed to help you make the most of raw materials, natural resources and manpower. Save money by consulting VISCO.

Ventilation

VISCO Ventilating and Air Conditioning Plant is specially designed for the varying requirements of all branches of Industry.

Fume Removal

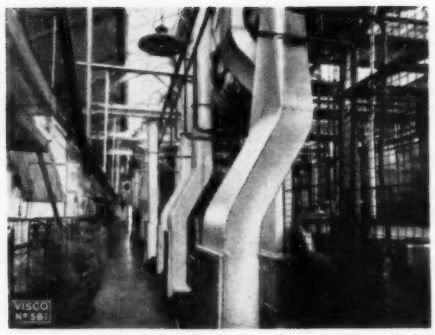
VISCO deal directly with noxious fumes and are used by leading industries for fume removal and air treatment installations.

Air Cleaning

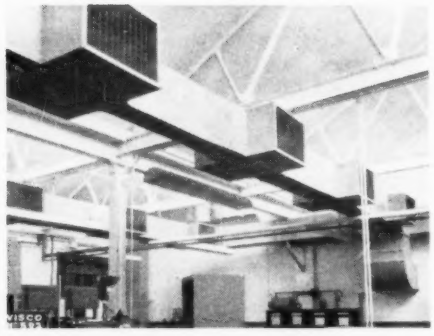
VISCO air filters – static and self cleaning – are used for air cleaning, conditioning and ventilation.

VISCO ENGINEERING CO. LTD.
Stafford Road, CROYDON
Croydon 4181

Ventilation, Fume Removal, Air Cleaning



Ventilation Plant
Walton & Brown Ltd.



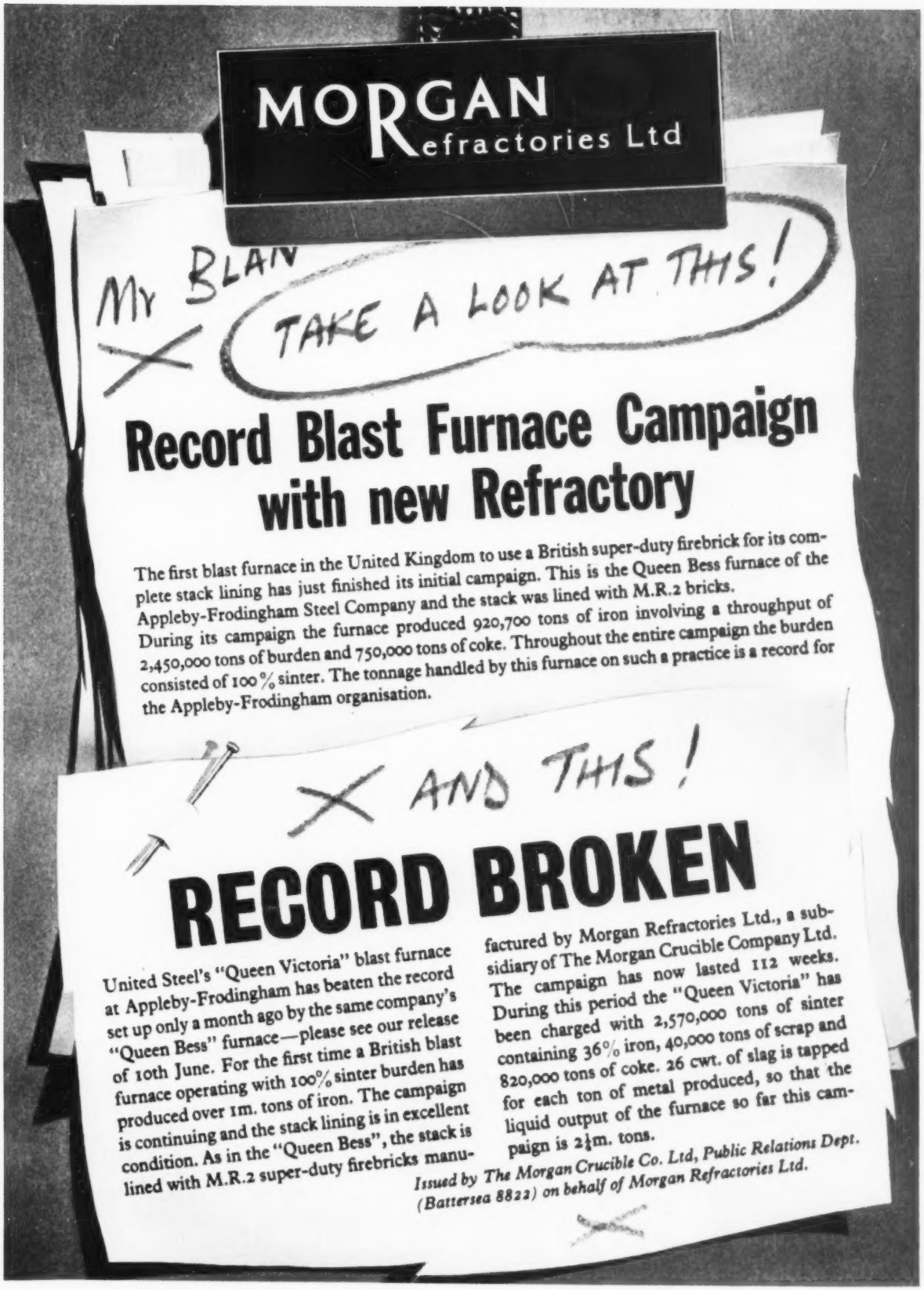
Air Conditioning Plant
The General Electric Co. Ltd.

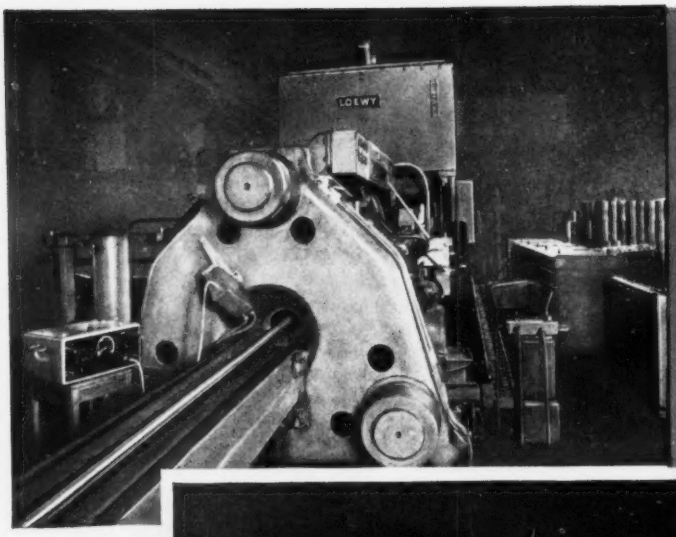
Heating and Ventilation Plant
May & Baker Ltd.

VISCO

Specialist Engineers to Industry

FWS

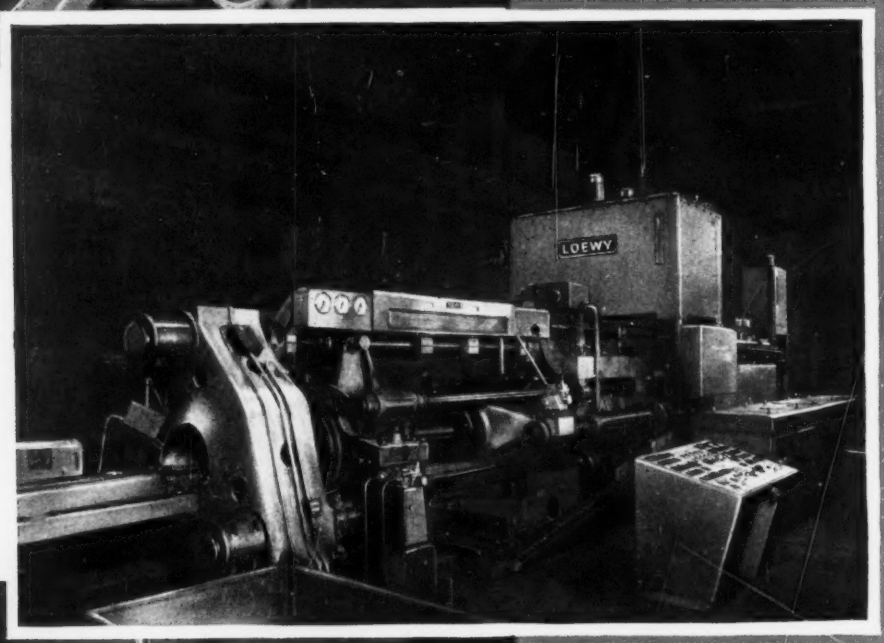

MORGAN
Refractories Ltd
Mr BLAIR
TAKE A LOOK AT THIS!
Record Blast Furnace Campaign with new Refractory
The first blast furnace in the United Kingdom to use a British super-duty firebrick for its complete stack lining has just finished its initial campaign. This is the Queen Bess furnace of the Appleby-Frodingham Steel Company and the stack was lined with M.R.2 bricks.
During its campaign the furnace produced 920,700 tons of iron involving a throughput of 2,450,000 tons of burden and 750,000 tons of coke. Throughout the entire campaign the burden consisted of 100% sinter. The tonnage handled by this furnace on such a practice is a record for the Appleby-Frodingham organisation.
AND THIS!
RECORD BROKEN
United Steel's "Queen Victoria" blast furnace at Appleby-Frodingham has beaten the record set up only a month ago by the same company's "Queen Bess" furnace—please see our release of 10th June. For the first time a British blast furnace operating with 100% sinter burden has produced over 1m. tons of iron. The campaign is continuing and the stack lining is in excellent condition. As in the "Queen Bess", the stack is lined with M.R.2 super-duty firebricks manufactured by Morgan Refractories Ltd., a subsidiary of The Morgan Crucible Company Ltd. The campaign has now lasted 112 weeks. During this period the "Queen Victoria" has been charged with 2,570,000 tons of sinter containing 36% iron, 40,000 tons of scrap and 820,000 tons of coke. 26 cwt. of slag is tapped for each ton of metal produced, so that the liquid output of the furnace so far this campaign is 2¼m. tons.
Issued by The Morgan Crucible Co. Ltd, Public Relations Dept. (Battersea 8822) on behalf of Morgan Refractories Ltd.
ME 166/A

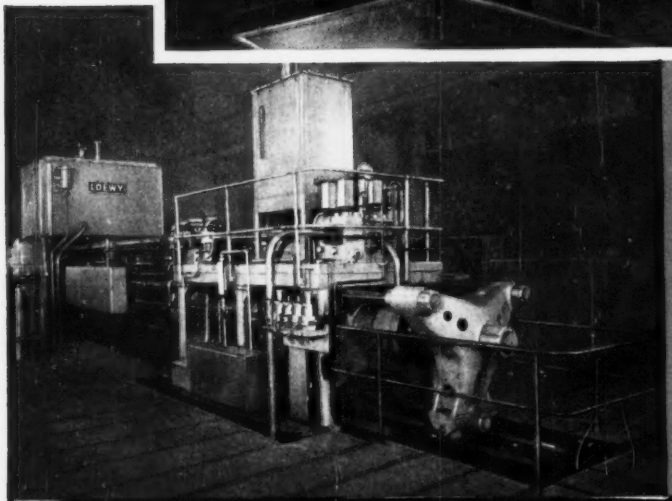


1250 TONS AUTOMATIC OIL HYDRAULIC EXTRUSION PRESS FOR RODS AND TUBES

supplied to

Vereinigte Deutsche Metallwerke
Frankfurt/Heddernheim, Germany

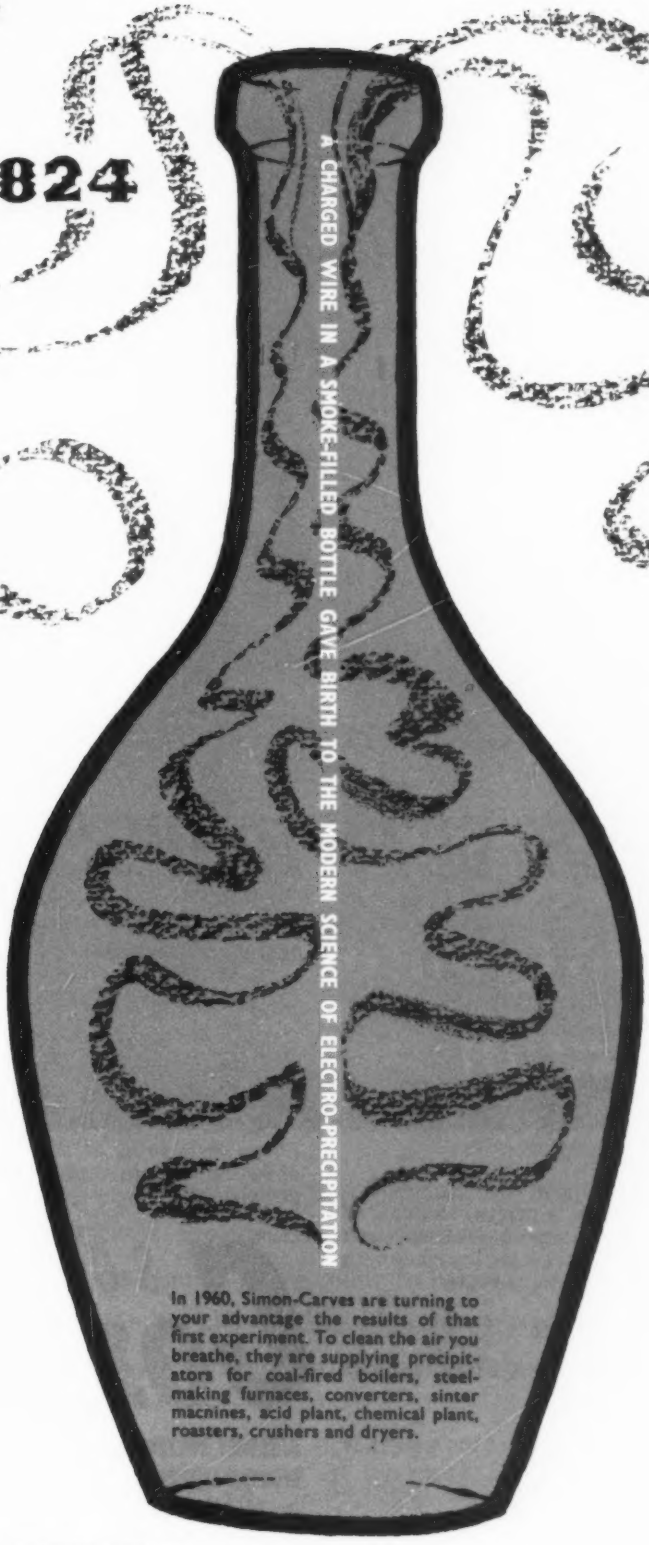




This press is equipped with an entirely new speed control system enabling "ISOTHERMAL" extrusion to be carried out
(Patents applied for)

THE LOEWY REG'D. TRADE MARK ENGINEERING COMPANY LTD.
BOURNEMOUTH ENGLAND

IN 1824



In 1960, Simon-Carves are turning to your advantage the results of that first experiment. To clean the air you breathe, they are supplying precipitators for coal-fired boilers, steel-making furnaces, converters, sinter macnines, acid plant, chemical plant, roasters, crushers and dryers.

HIGH-EFFICIENCY ELECTRO-PRECIPITATION BY

Simon-Carves Ltd

STOCKPORT, ENGLAND

and at CALCUTTA · JOHANNESBURG · SYDNEY · TORONTO

The "Margam Abbey"—built for the Port Talbot Pilotage Authority by Richard Ironworks Ltd., in which Cor-Ten was used extensively. Photograph by courtesy of the Port Talbot Pilotage Authority

COR-TEN GOES DOWN TO THE SEA IN SHIPS

At sea as well as ashore new uses are constantly being found for SCW Cor-Ten. It was used extensively in the construction of this vessel for the Port Talbot Pilotage Authority.

The Main Deck and Bulwark Plating
Shell Plating and Anchor Recess
Floors and Engine Seating
Chain Locker
Fresh Water Tank
Bulkhead Bottom Plating
Rudder Side Plates

—were made entirely from Cor-Ten. A typical example of the growing use of Cor-Ten in marine construction, and in other fields where high yield strength, together with outstanding resistance to corrosion, is vital.

COR-TEN IS TOUGHER

Weight for weight, the yield strength of SCW Cor-Ten is 50% higher than ordinary mild steel.

Alternatively—
Strength for strength, a saving of 1/3 of the weight is possible.

4–6 times more resistant to atmospheric corrosion.
Highly resistant to abrasion and fatigue.

COR-TEN SAVES MONEY

Initial costs are spread over a longer service life.

Maintenance costs are reduced.

Operating costs are lowered—in transport, payloads are bigger because of reduction in tare weight.

Please write to us at the address below for further information or for technical assistance in the application of SCW Cor-Ten to your products.

S·C·W BRAND Cor-Ten

RAILWAY ROLLING STOCK. AGRICULTURAL AND EARTH-MOVING EQUIPMENT. MINE CARS. FOWER STATIONS INSTALLATIONS. BARGES AND SMALL CRAFT

THE STEEL COMPANY OF WALES LIMITED

ABBEY WORKS, PORT TALBOT, GLAMORGAN. TELEPHONE: PORT TALBOT 3161

After "Aspects of Deep Sea Biology" N. B. Marshall (Hutchinson 1954)

These deep sea fishes generate their own electric lighting for next to nothing. This is more than *you* can do, but you *can* keep the cost of your lighting down by having the right lamps in the right fittings in the right places. We're ready to help you with your lighting problems and we'll be happy to send you a booklet dealing with the type of lighting that interests you. Just drop us a card asking for the appropriate catalogue: Commercial, Industrial, Floodlighting or General Service Lamps.

SIEMENS EDISWAN LAMPS AND LIGHTING

38/39 Upper Thames Street, London, E.C.4 · Telephone: CENtral 2332

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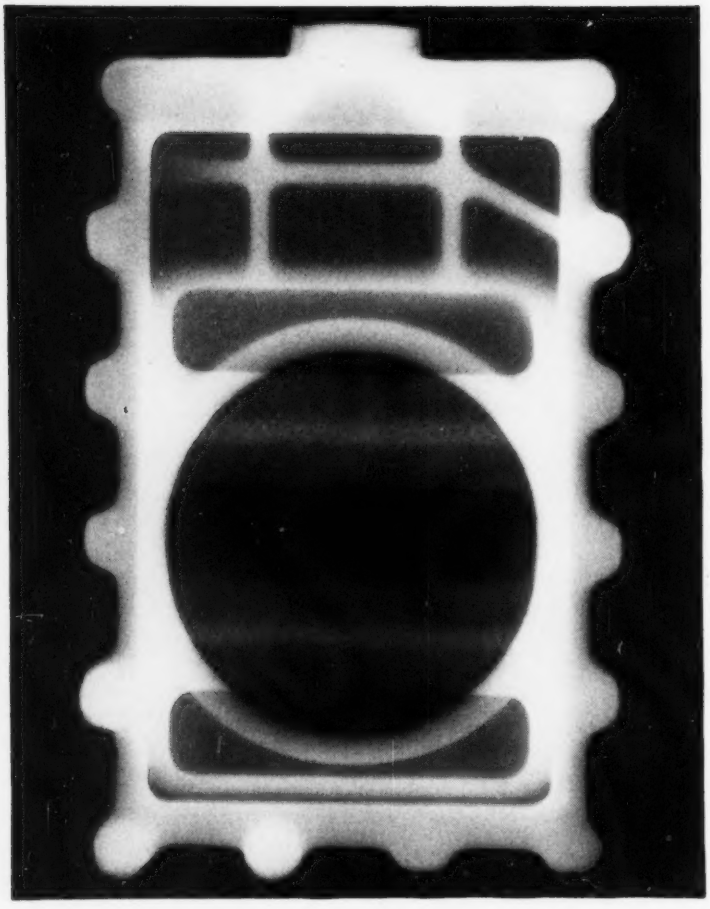

Where sections vary greatly . . .

. . . 2 films are better than 1

ILFORD technicians pioneered multiple film technique in industrial radiography. This has been graphically described as a "sandwich" of two or more films, and the technique gives vastly superior results where specimens with widely varying densities have to be critically examined.

The "sandwich" consists of two or more films of different speeds loaded into a standard cassette for simultaneous exposure. Thick sections of the specimen register clearly on the faster film, and the thinner sections on the slower film. The effects of differential exposure can be accentuated by using lead screens in the "sandwich". The technique can also be used for making duplicate radiographs by using two films of the same speed.

Choice of the appropriate ILFORD Industrial X-ray films obviously depends on the subject, the tube voltage and the presence or absence of screens. Full details of film choice and voltages, as well as lead screens, will be forwarded by request.

For improved radiographic examination

ILFORD INDUSTRIAL X-RAY FILMS, CHEMICALS, CASSETTES AND LEAD SCREENS

ILFORD LIMITED • ILFORD • ESSEX

Pouring Hot Metal in a 200 Ton Open Hearth Furnace, Abbey Works, The Steel Co. of Wales, by courtesy of whom this photograph is reproduced

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FOR OPEN HEARTH APPLICATIONS

REAVELL & CO. LTD.

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Reavell-Askania Regulators. Instrument Panels. Complete Instrument and Control Schemes designed, installed & commissioned. Project studies and reports.

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Stress Relieving Furnaces

We have a wide experience
in the design and installation of
large bogie hearth furnaces for the
general heat treatment of fabrications,
alloy steel castings and ingots.
Capable of taking loads up to 250 tons,
they can be fired by towns gas,
clean producer gas or oil
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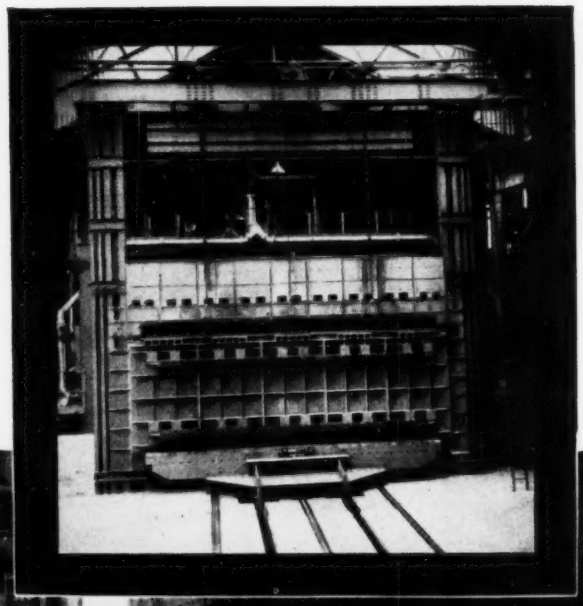
is possible throughout the chamber.



By kind permission of Steel, Peech & Tozer.

WINCOTT FURNACES

G.P. WINCOTT LIMITED SHEFFIELD, ENGLAND

Telegrams: WINCOTT, SHEFFIELD. *Telephone: 20211/2*

SBW19.

an M.P.

". . . I'm not the sort of chap to make headlines in Hansard and I don't suppose anyone would be daft enough to ask me to speak on Foreign Affairs or balance up a Budget.

"I've always been the back-bench type and I'm not a bit sorry. I learnt a long time ago that the only things ever produced by talking were gramophone records . . . and international incidents.

"Up at AW we like to get on with the job and leave hot air to the furnaces. Nobody has ever managed to *talk* steel into a mould and if our research boys thought that words would make a better Closeloy Roll they would have had us chucking dictionaries into the melt long before now—those lads never miss a trick.

"No! I reckon I'm a lot happier making rolls than I would be making speeches".

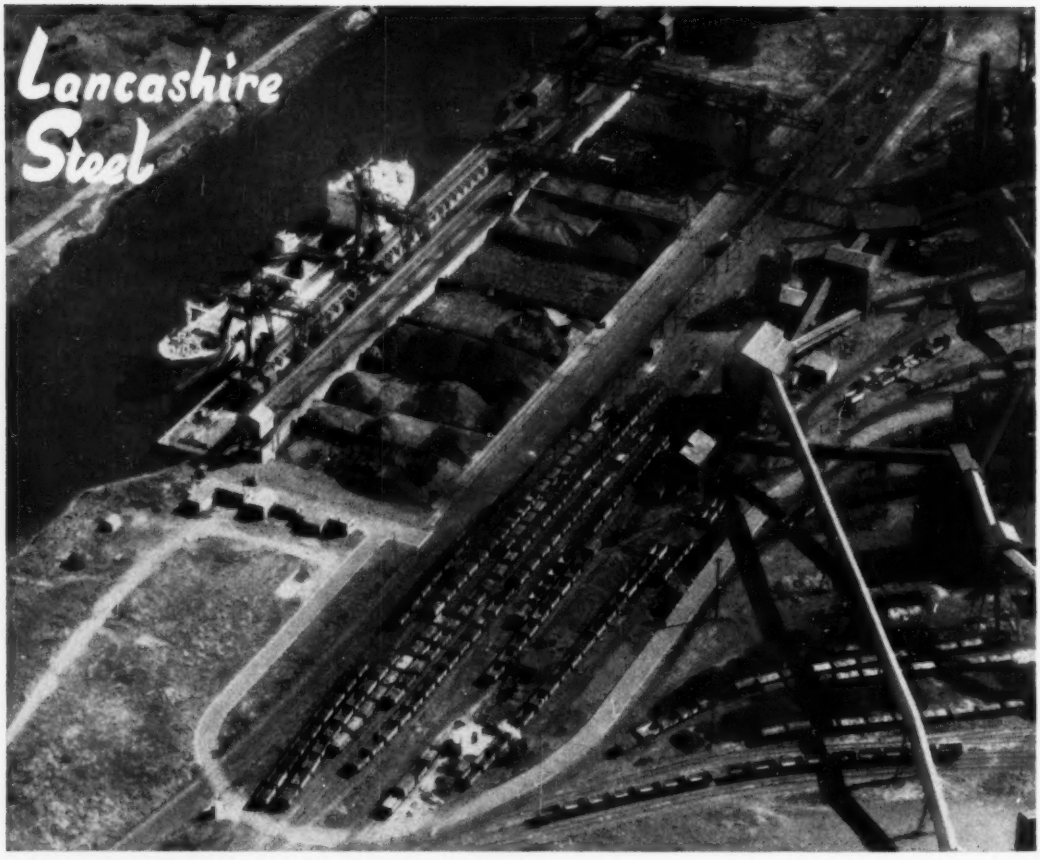
CLOSELOY ROLLS—perfection in Roll technique

AW

ARMSTRONG WHITWORTH (METAL INDUSTRIES) LIMITED

Close Works · Gateshead Upon Tyne 8 · Telephone: Gateshead 71261

Steel Foundry: Armstrong Whitworth (Metal Industries) Ltd.
Western Road Works · Jarrow · Co. Durham



AERIAL VIEW OF THE UNLOADING WHARF—*Photograph by Aero Pictorial Ltd.*

WIRE RODS
IN ALL QUALITIES

JOISTS ANGLES
CHANNELS TEES

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OTHER PRODUCTS

BASIC PIG IRON
FERRO-MANGANESE
TUBE STEEL
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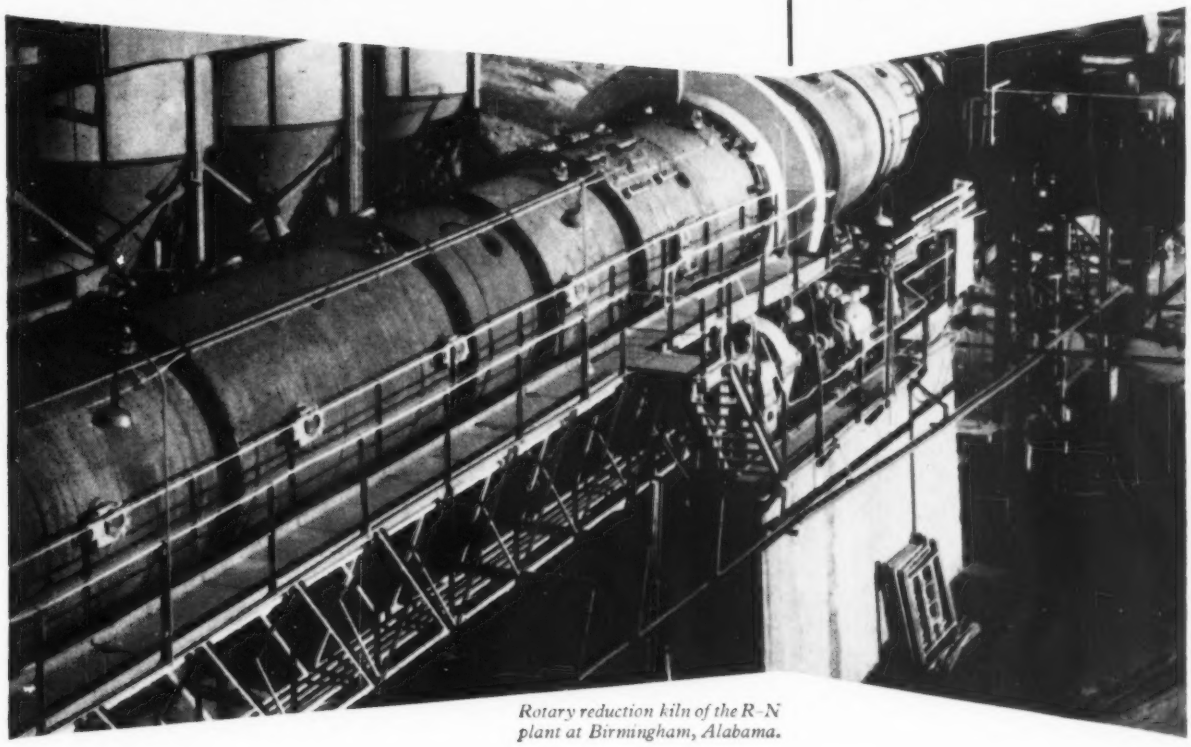
THE R-N PROCESS

for direct reduction of iron ore and subsequent wet separation of gangue



Rotary reduction kiln of the R-N plant at Birmingham, Alabama.

R-N Product replaces pig iron as well as scrap

The R-N Process provides the world's steel industry with a new steel furnace feed material from ores of nearly all types by direct reduction utilizing various types of solid, low-cost fuel and surplus gas if available.

The wet magnetic separation after reduction removes the ore gangue and the concentrate obtained contains usually more than 90% Fe as metal, less than 3% SiO_2 and only a smaller part of the phosphorus of the ore.

The sulphur content of the concentrate is below 0.05%.

The concentrate is dried and formed into briquettes.

The capital cost of an R-N plant is about half that required for a blast furnace complex of corresponding size, and the production cost for R-N metallic iron briquettes will be considerably lower than that for pig iron.

Low stable price and uniform composition make R-N iron an excellent and competitive substitute for scrap.

The development of the R-N process to a commercial process is the result of collaboration between the Republic Steel Corporation and the National Lead Company through the R-N Corporation, New York.

Representative for Europe

R-N PROCESS AGENCY

162 Avenue Louise, Brussels 5, Belgium

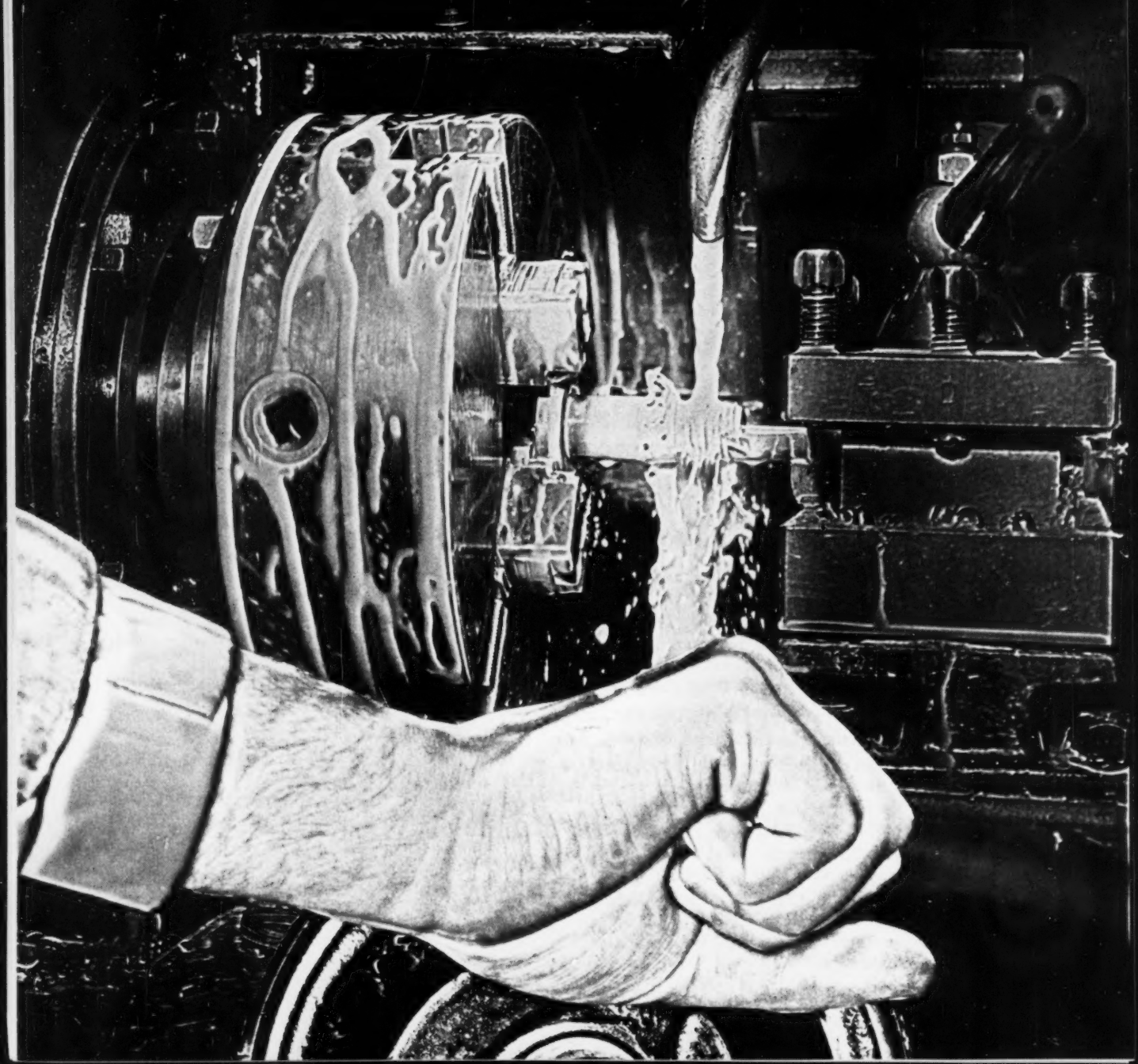
Tel: 48.81.30

Recommended Engineering Company

HEAD WRIGHTSON MINERALS ENGINEERING LTD.

46 Rutland Park, Sheffield 10

Greater safety for hands



With new Shell Dromus Oils

Most modern soluble cutting oils contain phenolic compounds used as coupling agents between the oil and the emulsifier, for better blending and easier mixing. These phenolic compounds can cause skin irritation, especially where modern high-speed machines are used and the emulsion can concentrate, through the evaporation of water, above the safety level.

Shell research chemists have been working on this problem, which has been causing some concern to Management. After considerable research, Shell Dromus Oils have been reformulated and these new cutting oils now produce bland emulsions, which considerably reduce the risk of skin trouble to operators.

The real difficulty was to find a new coupling agent to replace the phenolic compounds, and Shell finally used what their chemists know as a higher fatty alcohol complex. This solved one problem, but presented another. The new coupling agent was volatile at the high temperatures normally used in blending processes. Further research found a solution to this problem by designing and installing new plant.

The new Dromus Oils are every bit as efficient as before and cost no more. They put Management in the welcome position of being able to minimise working hazards at no extra cost. And machine men need no longer be so worried about skin troubles.

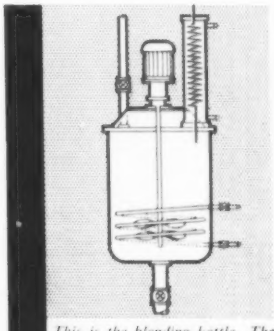
The moral of the story is that Shell research is supremely applicational. The centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organisation have any major lubricating problems, it pays to get in touch with your local supplier of Shell Industrial Lubricants.

The Research Story

Shell chemists in the U.K., in Holland and in the U.S.A., prepared and examined hundreds of experimental soluble oils, and established that certain combinations of fatty alcohols could be used in place of phenolic compounds with no loss of efficiency. They set to work to discover the best combination and developed a higher fatty alcohol complex which fitted exactly. Then they realised that to blend this new coupling agent into soluble oils would require special plant and new blending techniques.

Exhaustive testing of blend stability, emulsion stability, anti-corrosion and machining properties led to selection of the most promising blends. A pilot plant was set up to produce batches of these for use in field trials.

This field testing and final development proceeded for two years whilst production plants were erected at points so chosen as to give the most economical and rapid delivery throughout the United Kingdom.



This is the blending kettle. The reflux condenser beside the stirrer motor prevents the loss of constituents volatile at the blending temperature.

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Bulk Log Handling

Mitchell conveyors at Bowaters' Mersey Division carry 100 tons of logs an hour...

The problem of conveying and stacking logs in really large quantities is comparatively new to this country. Yet Mitchell Engineering's recently completed external conveyor system at Bowaters' Mersey Division handles over 100 tons of logs an hour.

This vast capacity is attained by an efficient arrangement of chain and belt conveyors, 1,250 ft in total length, which carry logs either straight to the pulping mill or to a storage pile. The logs carried straight to the mill pass through a debarking plant and provision is made for re-circulating any log not properly debarked. Logs for the storage pile are carried up a 120 ft mobile stacker.

Mitchells are active in the field of boiler design, cableways and ropeways, wagon handling, transporters and conveyors, cranes, mills, ship loading plant and nuclear power.

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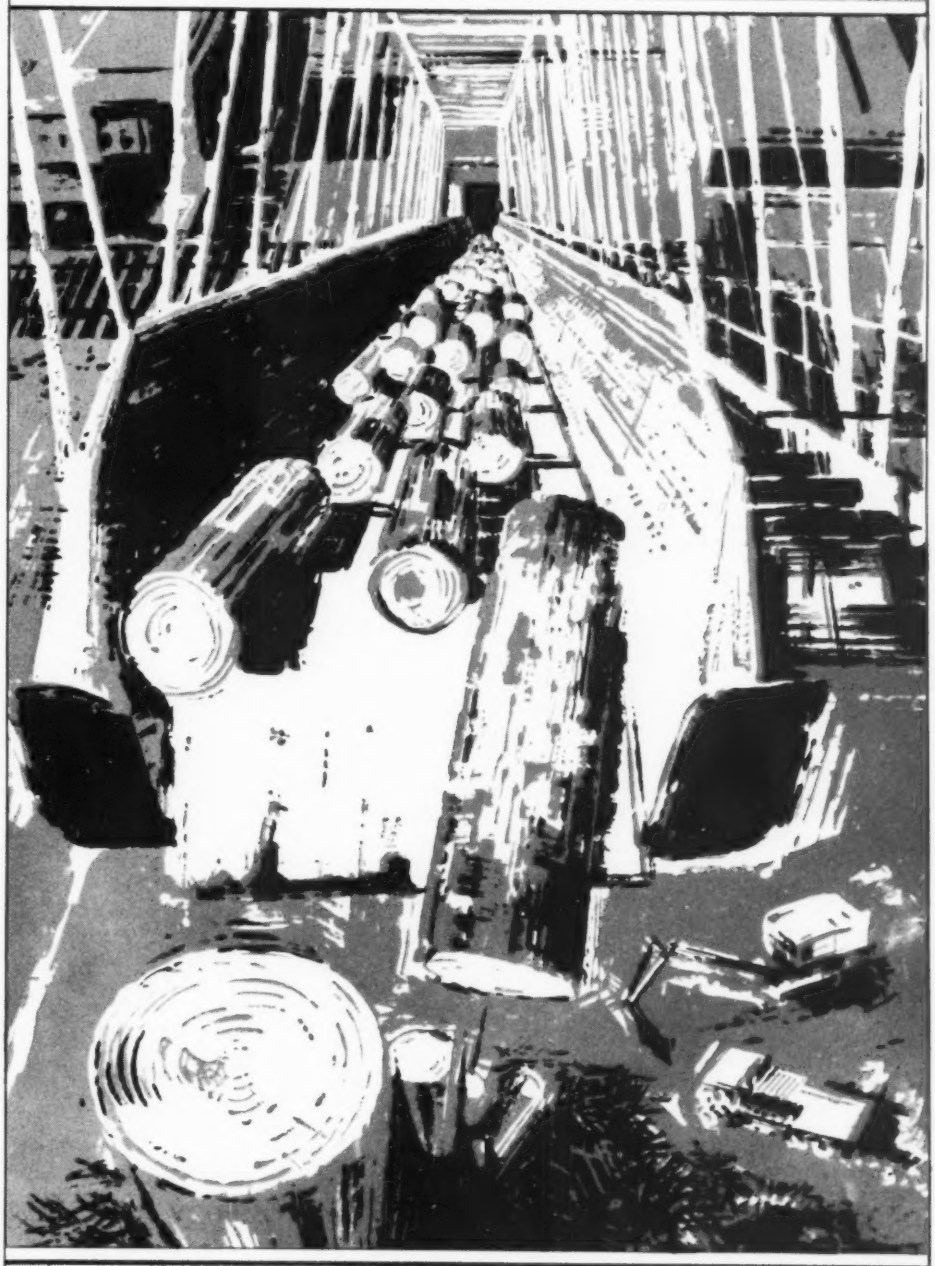
The mobile stacker seen in operation here has already handled over 168,000 tons of logs



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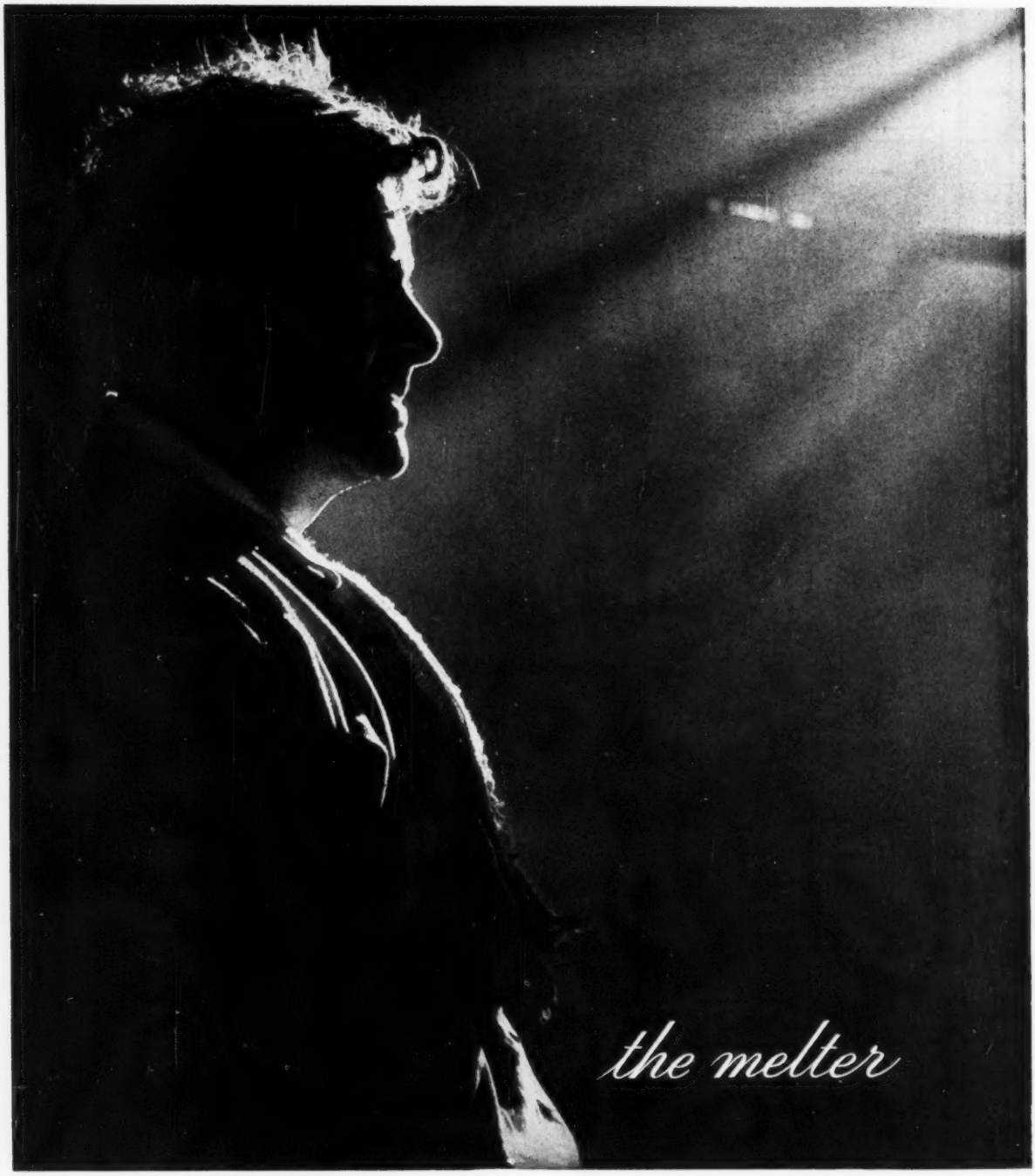

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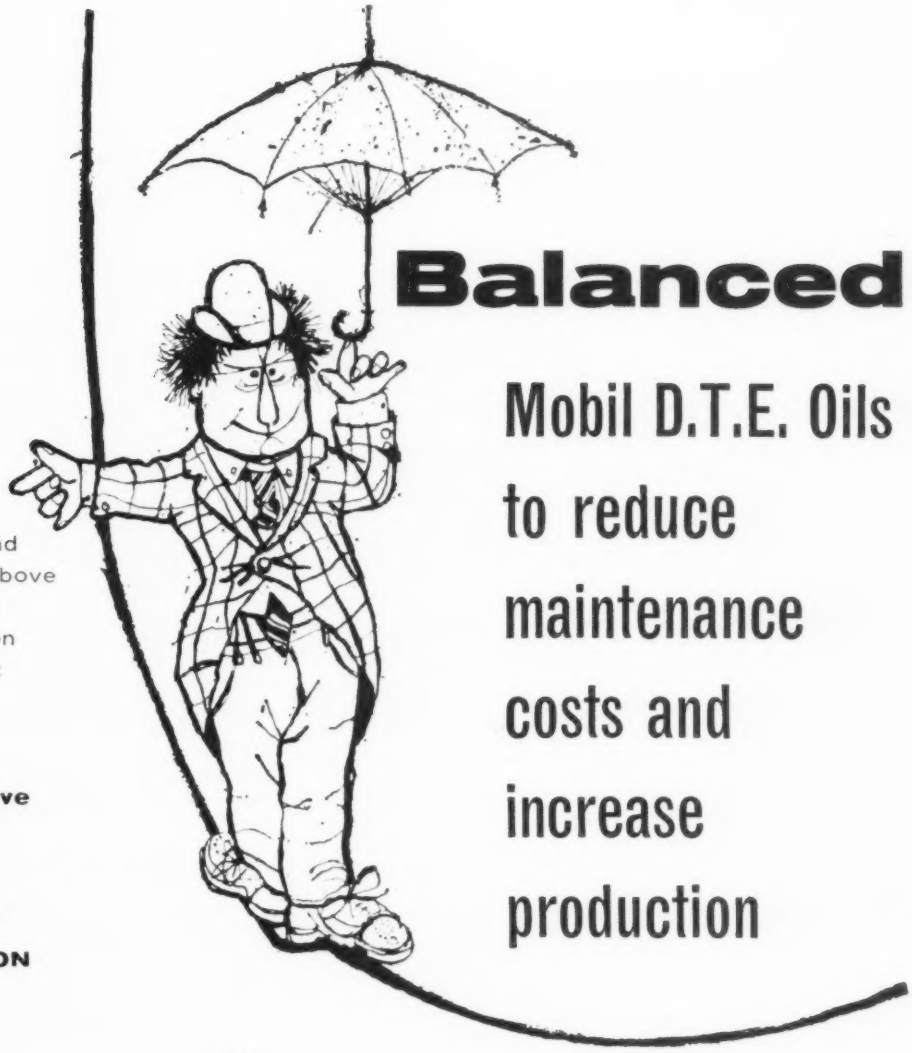

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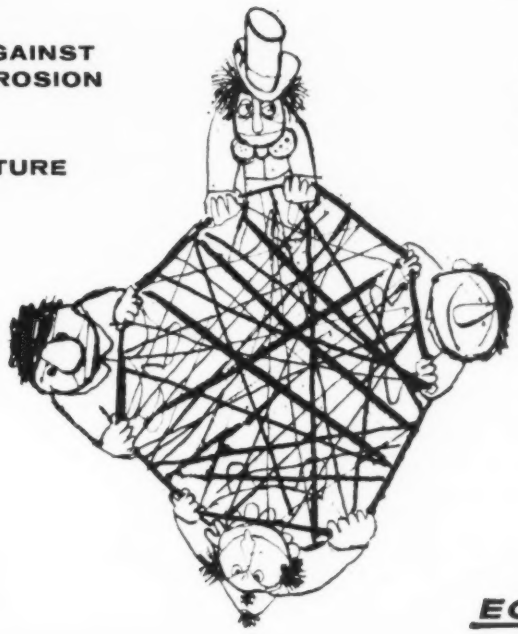

ASK THE MAN FROM MOBIL ABOUT BALANCED OILS

Our representative will give you the facts—the facts about the performance of Mobil D.T.E. Oils in comparison tests with other well-known hydraulic and circulating oils. Ask the man from Mobil to call and explain how Mobil D.T.E. oils can reduce maintenance costs and increase production

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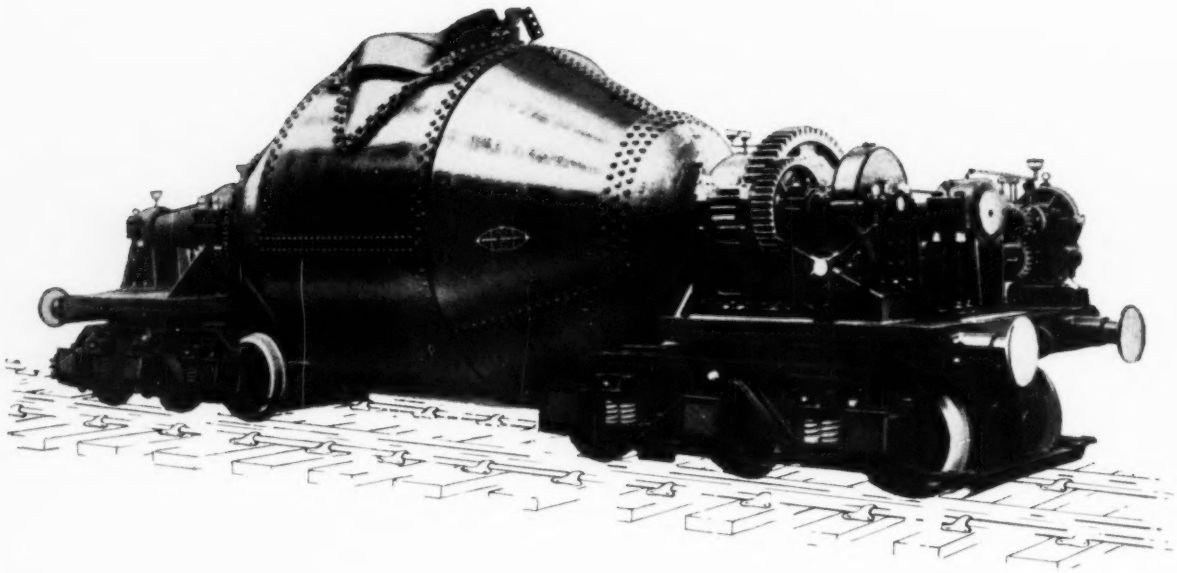

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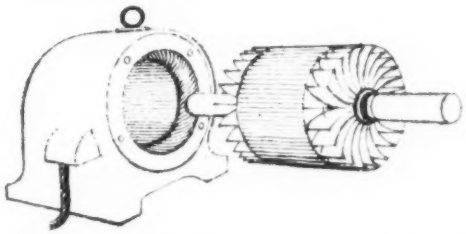
Electric Motors & Controls 1

Most manufacturers today employ electric motive power through individual drives, which, among their many advantages, permit the right type of motor to be used for each of various types of machine. The range of motors available—each with its own characteristics–is very large, and the factory executive could well be guided in his choice by the expert views of the motor manufacturer, the installing engineer or his Electricity Board's engineer. The characteristics of the main types of motor are briefly summarised below.

Squirrel-cage Motors

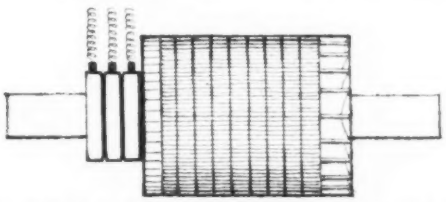
These are the most straightforward and simple in design, and are therefore relatively cheap and robust in character. They should be considered for general duties and, in conjunction with variable-speed gears or couplings, for applications requiring variable speeds, e.g. for crane drives. Small sizes can be switched direct-on-line.



The squirrel-cage motor is very suitable for individual drive of each motion of single-purpose machine tools where the motor horsepower can be precisely specified. It is suitable for driving pumps, fans, lifting hoists and woodworking machines. Textile machinery represents another field of use.

Slip-ring Motors

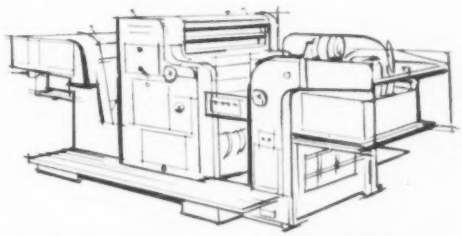
The chief advantage of the slip-ring motor is a very low starting current for a given torque, e.g. full-load torque at starting with a current about 10% above full-load current. This makes it suitable for applications requiring a prolonged starting period with a



load of high inertia. It also permits of speed variation below synchronous speed, though with some loss of efficiency. Typical applications include fans, pumps, heavy lathes, grinders and boring mills, as well as calendering machines, cable-laying-up machines and mine hoists.

Three-phase A.C. Commutator Motors

The main characteristic of this type is variable-speed with uniform and gradual acceleration and good efficiency over the speed range. Paper manufacture provides excellent examples of its use, e.g. in paper-making, reeling, cutting, calendering, coating and drying.



A.C. commutator motors are recommended for mechanised bakeries and for cranes and hoists where very slow speeds are frequently needed.

Synchronous Motors

These are constant-speed motors. One particular advantage is that they can be operated at unity or even at leading power factor to correct a system suffering from lagging power factor, and perhaps so qualify for a reduction in the electricity bill. Pump and compressor drives are typical uses to which they can be put. They are also used in motor-generator sets.

Single-phase A.C. Motors

In general, single-phase motors are used in light industries for drives not requiring more than about five horsepower or where a three-phase supply is not available. While their use is mainly limited to work of a light nature, they do fill a need in such duties as sewing-machine drives, portable hand tools, window opening and closing gear, etc.

Direct Current Motors

For a completely unfettered performance where wide ranges of speed variation, high rates of acceleration and powerful dynamic braking are all-important, the D.C. motor is unrivalled. This means in effect the installation of an A.C.-D.C. motor-generator set or rectifier to give the necessary supply, but the increased cost may well be compensated by the improvement in productivity. When variable voltage is applied to the armature, a wider speed range is obtainable than with any other type of motor. Typical applications of the D.C. motor are: cranes, haulage and tippler equipment, certain machine tools requiring a large speed range and smooth acceleration, high-speed printing and steelworks drives.

For further information, get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London, W.C.2. TEMple Bar 9434.

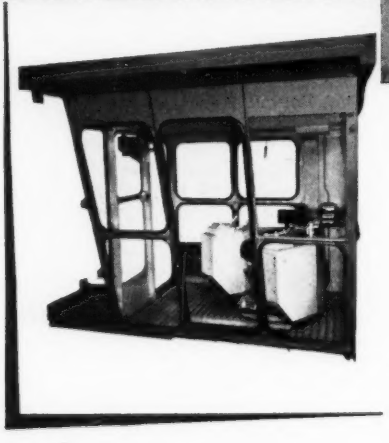
They can offer you excellent reference books on electricity and productivity (8/6, or 9/- post free)—"Electric Motors and Controls" is an example.

E.D.A. also have available on free loan within the United Kingdom a series of films on the industrial uses of electricity. Ask for a catalogue.

7914

JOSEPH ADAMSON

ELECTRIC OVERHEAD TRAVELLING CRANES



★ *a view of the cab showing the seat control unit.*

The Adamson 50/10 ton crane is the third of a series of new design supplied to Richard Thomas & Baldwins Limited, Ebbw Vale Section. Features of the crane include monolithic construction of the crab and the elimination of castings by mild steel fabrication of the hoist barrel and bottom block. The cab is of particular interest as it incorporates the most modern type of seat unit ensuring maximum vision and ease of control. Joseph Adamson electric overhead travelling cranes can be supplied to all specifications including cranes suited to the most exacting 24 hours-a-day process work.

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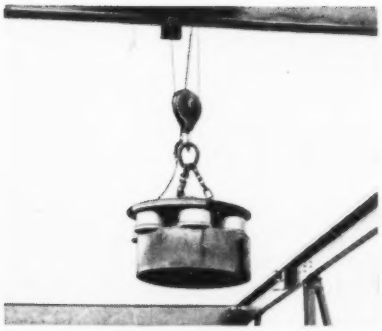
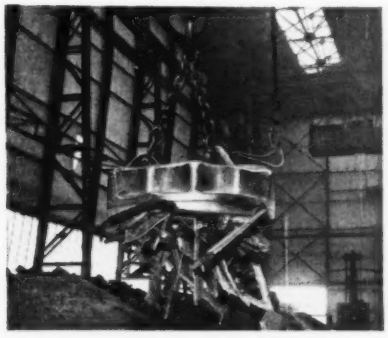
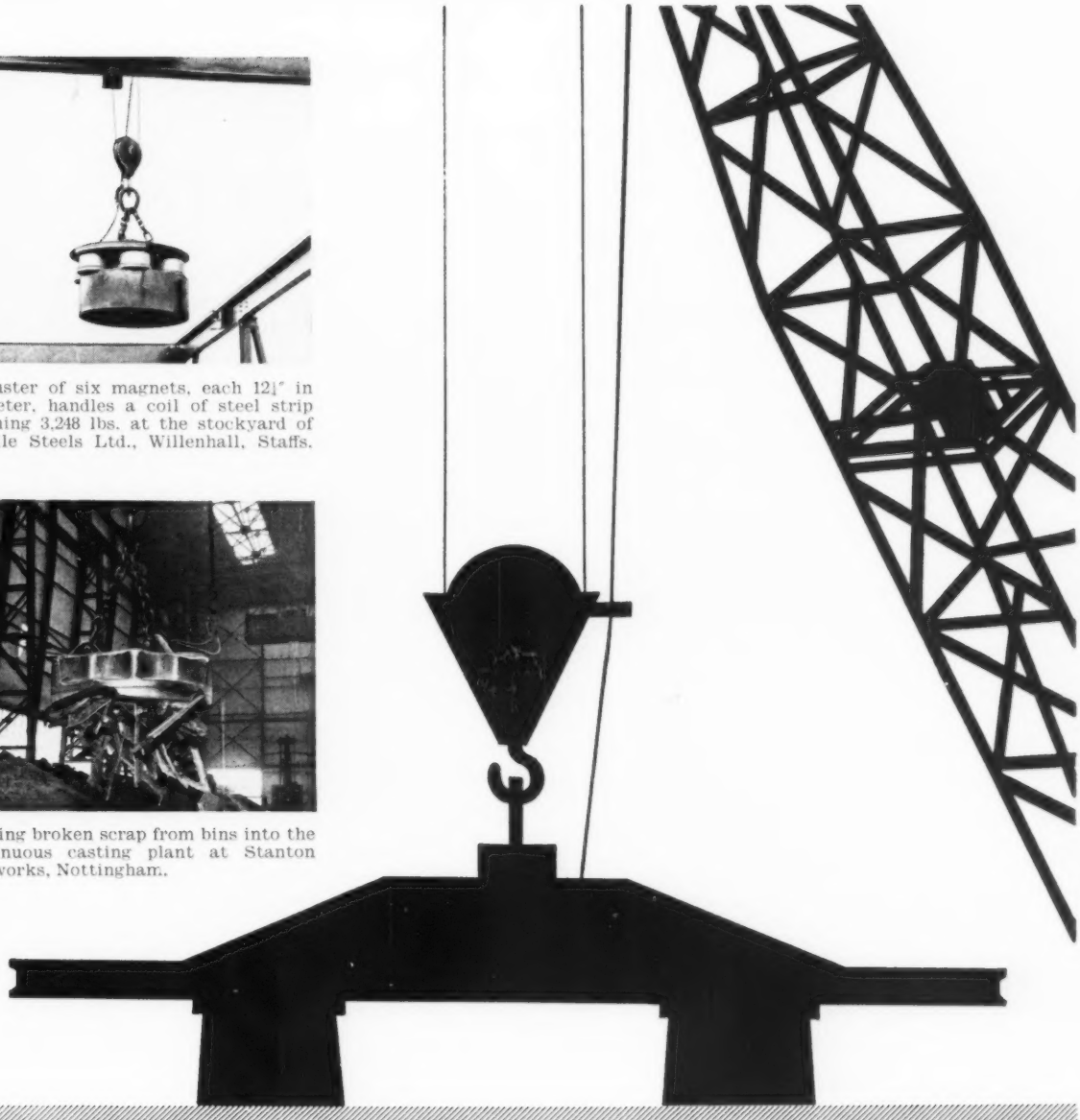


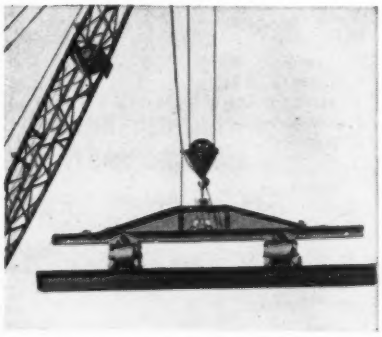
A cluster of six magnets, each 12¼" in diameter, handles a coil of steel strip weighing 3,248 lbs. at the stockyard of Ductile Steels Ltd., Willenhall, Staffs.



Loading broken scrap from bins into the continuous casting plant at Stanton Ironworks, Nottingham.



WITTON-KRAMER LIFTING MAGNETS FOR EVERY JOB



Two bi-polar magnets on spreader beam lifting rolled steel joist.

Whether handling hot steel billets and ingots or salvaging metal from under water, Witton-Kramer electric magnets do the job superbly. Circular, rectangular or bi-polar, G.E.C. makes them all with coils designed and constructed to withstand heavy duty and shock loads. All Witton-Kramer magnets are easily maintained and quickly serviced.

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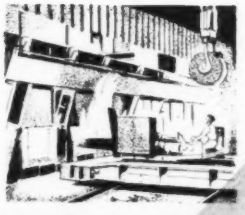

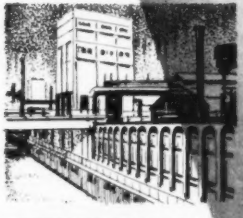

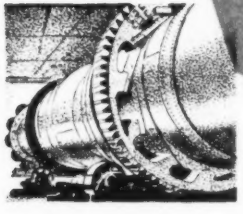

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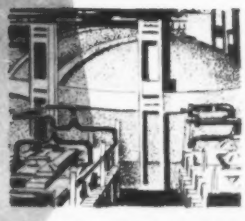

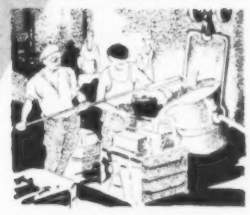

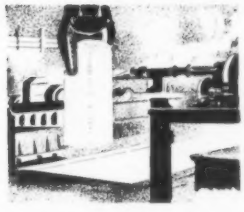

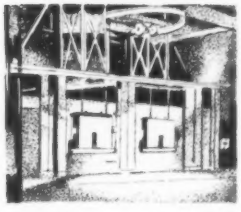

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Subscriptions
Members: free
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DAVY-UNITED ARE BUILDING BOTH STRIP MILLS

Two new Hot Strip Mills are now being built in Britain—the first at the Ravenscraig Works of Colvilles Limited: the second at the Spencer Works at Newport, Mon., of Richard Thomas and Baldwins Limited. Davy-United have been entrusted with the building of both of them.

The famous Hot Strip Mill at the Ebbw Vale Works of Richard Thomas & Baldwins Limited, the first in Europe, which Davy-United also helped to build.

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359/DU

P. E. HOLLOWAY

PHILIP EVERETT HOLLOWAY was born in 1907 at Marton-in-Cleveland, Yorkshire, and educated at Sherborne School, Dorset. He entered the iron and steel industry in 1924 as a commercial trainee with the Cargo Fleet Iron Company, but two years later transferred to the works and trained in the blast-furnaces, steelworks, and rolling mills. He was appointed night manager at Cargo Fleet in 1930.

In 1932 Mr Holloway joined the Irlam Works of The Lancashire Steel Corporation Ltd as assistant works manager, and in 1936 he became works manager.

From 1945 to 1946 he was a member of the Allied Control Commission in Germany. He then returned to The Lancashire Steel Corporation Ltd and in 1950 became a director. When the company was reorganized in 1958 Mr Holloway was appointed to his present post of managing director of the Lancashire Steel Manufacturing Company Ltd.

Mr Holloway's wide interests are indicated by the number of companies on which he serves as a director. These include the Lancashire Steel Corporation Ltd, Lancashire Steel (Rhodesia) (Private) Ltd, Lancashire and Corby Steel Manufacturing Company Ltd, The Pearson and Knowles Engineering Company Ltd, Rylands Brothers Ltd, Whitecross Company Ltd, Rhodesian Iron and Steel Company Ltd, B.R.C. Steel Ltd, Hall Engineering (Holdings) Ltd, The United Kingdom Ferro-Manganese Company Ltd, and The Wellman Smith Owen Engineering Corporation Ltd. He is a member of the Council and Executive Committee of the British Iron and Steel Federation, and in addition serves on the Accident Prevention Committee, Raw Materials Coordinating Committee, Training Committee (he is also chairman of the Lancashire Area Training Committee), Rod Rollers Committee, Pig Iron Producers Conference, and the Basic Pig Iron Producers Conference.

Mr Holloway joined The Iron and Steel Institute in 1933 and was elected to the Council in 1960.

P. E. Holloway
Member of Council

Rupture of silicon–iron sheets and related creep phenomena

C. W. Chen, B.Sc., M.Sc., Ph.D.

SYNOPSIS

The processes of necking, void formation at grain boundaries, and the development of edge cracks paired at opposite sides lead to three different modes of rupture between 550° and 875°C. Intercrystalline cracking is only prominent below 650°C, while necking dominates rupture at higher temperatures. The major structural changes during creep may be variously, migration and serration of grain boundaries, polygonization, recrystallization, and grain coarsening, according to different temperatures. An increase of ductility associated with the necking-initiated rupture mode has been ascribed partly to the thermally activated process of creep and partly to polygonization. MgO *surface coating raises the creep resistance and reduces the susceptibility of sheets to void formation. The latter effect has been related to the development of subgrain boundaries. The suppression of void formation in polygonized matrix has been accounted for in two models.* 1875

AN EXTENSIVE INVESTIGATION of intercrystalline cracking at elevated temperatures has shown that many metals and alloys rupture through the formation of voids at grain boundaries.[1] This process, however, fails to dominate rupture at high temperatures on numerous occasions. For instance, Sully and Hardy reported that besides void formation, necking was also a major process of rupture for Al–Cu alloys.[2] Moreover, certain structural changes such as lattice bending[3] and grain-boundary migration[4] can minimize the void formation.

The relationship between void formation and necking was not elucidated in the study of Sully and Hardy. Recently, Nemy and Rhines found that these two processes operated independently at different stress levels. Because of the complex nature of creep, other factors, either structural or environmental, may play vital roles in the rupture of metals.

The present investigation deals with various high-temperature rupture modes and related creep phenomena, with special attention to the structural change and the effect of a surface coating. Silicon–iron in sheet form was chosen as the test material because the substructure of Si–Fe could be easily revealed by electrolytic etching. Furthermore, sheet specimens permitted a close study of the void formation with respect to the creep curve.

EXPERIMENTAL TECHNIQUES

The Si–Fe sheets used contained 3·25 wt-%Si and less than 0·1% impurities. A (110) [001] texture was developed as a result of cold rolling and annealing. Most grains were about 1 mm dia. and fairly uniform in size. In the as-received condition, the sheets had a 0·0005 in. thick MgO coating on the surface. The coating could be removed first by heating the strips at 850°C for several hours, and then by macro-etching them in fresh $FeNH_4(SO_4)_2$ solution at 80°C for 8–10 min.

Both coated and bare creep specimens of the conventional form for sheet metals were prepared with 3·75 × 1·0 × 0·012 in. gauge dimensions. All creep-rupture tests were conducted under constant loads in an argon atmosphere between 550° (about 20° below one half of the absolute solidus temperature of the alloy) and 875°C. Since the strips had been finally annealed at 1100°C, the grain structure was stable under no load in this temperature range. In the investigation of void formation, the tests were interrupted at various stages for macro-examination of the specimens. Electrolytic polishing and etching were performed under the same conditions previously described.[6]

RESULTS

Rupture mode

In the chosen temperature range (550°–875°C as mentioned), the rupture of the sheets falls into two major (I and II) and one minor (III) mode (*see* Fig.1). Strictly speaking, only mode I exhibits intercrystalline cracking, the others are partly transcrystalline. Mode I displays a jagged rupture surface and a large number of voids, indicating that macroscopic cracks are produced by the joining of intercrystalline voids. Necking is not pronounced, sometimes not even measurable. In contrast, necking in mode II is prominent, but void formation is not so distinguished as in mode I. The rupture surface is less jagged, but characterized by a large opening in the middle.

The characteristics of mode III are a lack of void formation and a wide opening of the rupture surface at both ends. Also, necking is not so predominant as in mode II. Obviously, rupture in this mode is due to the development of two edge cracks situated opposite each other. Such development of paired edge cracks offers two advantages in initiating rupture over single edge

Manuscript received 29 August 1960.
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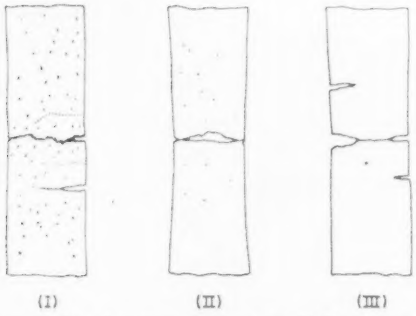
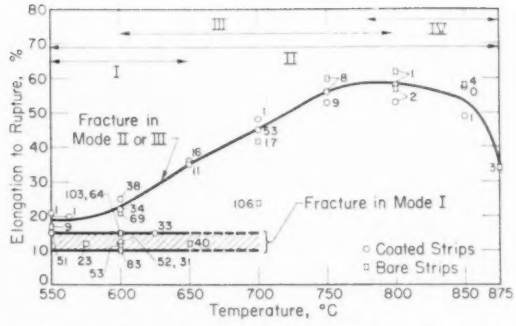


1 *Three modes of rupture observed on* Si–Fe *sheets between 550° and 875°C*



2 *Elongation to rupture and structural changes (I–IV) during creep at different temperatures. I Serration and confined migration of grain boundaries. II Polygonization. III Recrystallization. IV Grain coarsening. Numbers of voids developed in the ruptured specimens are indicated*

cracks. First, it raises the tensile stress in the cross-section of the cracks more efficiently. Second, it does not disturb the symmetry in the state of plane stress and strain, thereby enabling the cracks to propagate towards each other under the notch effect. Mode III occurs infrequently when edge cracks are accidentally produced in pairs. It is therefore considered a minor mode.

When the elongation to rupture is plotted against temperature (Fig.2) another difference is revealed among the rupture modes. While elongation measured in mode I is relatively low (10–15%) and apparently temperature-independent, ductility associated with modes II and III is higher and definitely temperature-dependent. Above 600°C, the elongation observed in the latter modes increases rapidly with temperature, it reaches a maximum value of 53–62% between 750° and 800°C, and then decreases above 800°C.

The rupture modes are based on three processes of rupture of the sheets, namely, necking, void formation at grain boundaries, and the development of paired edge cracks. Each process leads to a distinct rupture mode, but often more than one process act together to give a mixed mode. The formation of intercrystalline voids is particularly noticeable between 550° and 700°C. Its influence on rupture is likewise prominent below 650°C. At higher temperatures, rupture is solely dominated by necking.

Tertiary creep and void formation

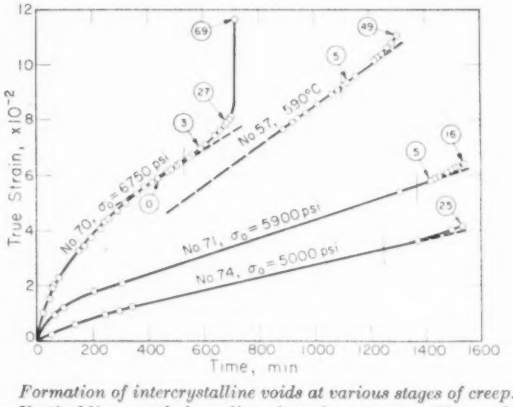
To understand the increase of ductility in rupture mode II, it appeared advisable to analyse the creep curves at various temperatures. Hence a set of creep curves were obtained at 600°, 700°, and 800°C with the initial applied stress (σ_0) so chosen that all specimens had about the same rupture life. The curves have been analysed in Table I. As temperature increases, the time in pre-tertiary creep (t_p) decreases while the tertiary creep time (t_t) increases; the strain associated with tertiary creep (ϵ_t) also increases markedly. Above 600°C, specimens elongate more during tertiary creep than all other stages combined.

Another important observation in tertiary creep is the development of voids. As shown in Fig.3, no holes penetrating the specimen are found at boundaries in steady-state creep at a magnification of $\times 15$. In other words, the formation of visible voids with diameters larger than 2×10^{-3} cm accelerates creep rate, thereby causing tertiary creep. This observation is in accord with the criterion that any undue structural change or mechanical instability will start tertiary creep. The present finding coupled with those of Greenwood, Miller, and Suiter[7] strongly indicates that the growth of voids is not expected to any appreciable extent before tertiary creep. Hence it is not surprising to note a great discrepancy between the rupture time and the theoretical growth time calculated by Hull and Rimmer[8] in their recent work.

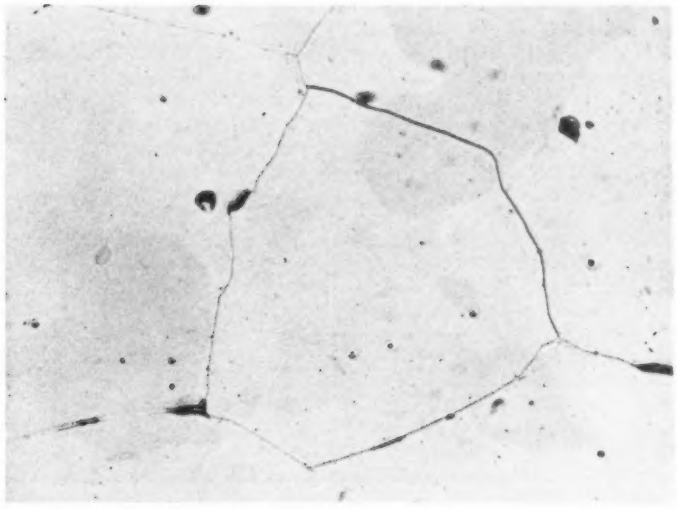
At 600°C, the true strain at which visible voids emerge is reduced with decreasing σ_0. Since this strain is essentially derived from steady-state creep (*see* Fig.3) and since the steady-state creep rate and σ_0 are directly related, it is deduced that lower steady-state creep rates enable voids to form at smaller strains. No simple relation is observed between σ_0 and the number of voids at rupture, which may be controlled by other factors such as grain orientation and grain-boundary morphology.[9]

Effects of MgO *coating*

Two effects have been disclosed of the surface coating of MgO on the creep-rupture behaviour of the sheets: (*a*) the creep resistance is effectively increased by the coating. For example, under $\sigma_0=8060$ lb/in^2 and at 600°C, the steady-state creep rate decreases from $5{\cdot}3\times10^{-2}$ h^{-1} for bare strips to $0{\cdot}63\times10^{-2}$ h^{-1} for coated strips, and (*b*) the coating reduces the suscepti-



3 *Formation of intercrystalline voids at various stages of creep. Vertical lines mark the ending of steady-state creep. Numerals in circles are the numbers of voids developed at the creep stages indicated by arrows. All tests except no.57 were conducted at 600±1°C*



4 *Grain-boundary migration confined at grain corners. Specimen tested at 650°C* ×200

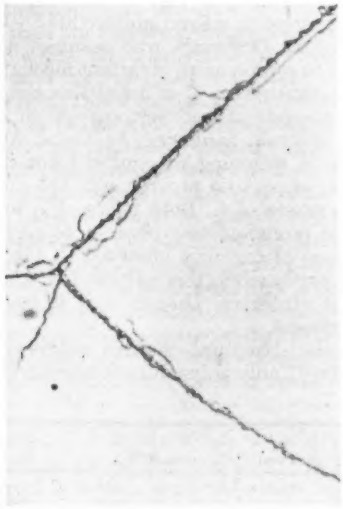
bility of the strips to void formation. In Fig.2, between 550° and 650°C, five out of six bare strips fail through void formation whereas most coated strips are ruptured by necking. As a consequence of both effects, a considerable extension of rupture life is achieved by the application of a refractory coating.

Structural change during creep

Creep brings about many structural changes in Si–Fe sheets. A temperature scheme of the major changes is superimposed in Fig.2 and the changes are described below:

Serration and confined migration of grain boundaries

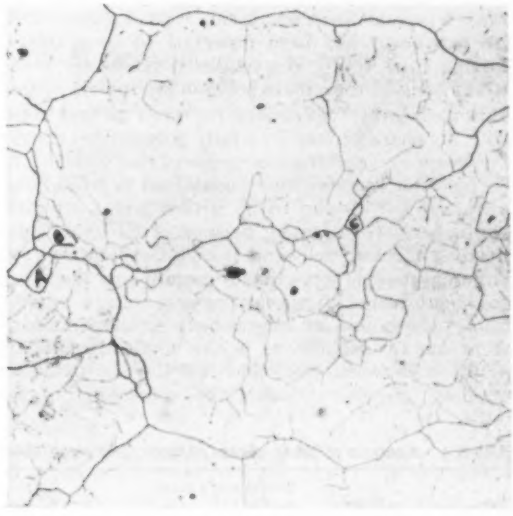
Upon stressing between 500° and 650°C, some segments of grain boundaries migrate over a small distance (Fig.4); while many others appear highly serrated. Most of the migrating boundary segments are around grain corners, signifying that the migration is strain-induced as a result of the blocking of boundary sliding at the junctions of grains.



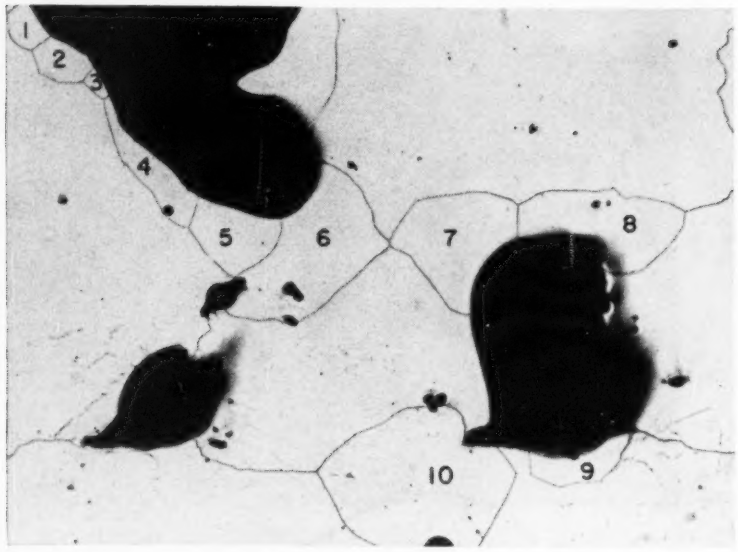
5 *Development of sub-boundaries at 550°C* ×600

Polygonization Specimens that have been ruptured at 547°C contain subgrain boundaries at some disturbed grain boundaries (Fig.5). At higher temperatures, sub-boundaries are formed at more grain boundaries and extend toward the interior of grains; the size of subgrains also increases (*see* Fig.6).

In a comparison of the grain structure of two sets of specimens that have been similarly tested but differently ruptured, it is noted that the apparent difference is the relative amount of surface area of grain boundaries to which fine sub-boundaries are attached. Specimens that ruptured after severe necking had most of their grain boundaries decorated with sub-boundaries whereas those ruptured via void formation were characterized by the absence of sub-boundaries at most of the grain boundaries. Thus the suppression of void formation may be ascribed to the formation of sub-boundaries at grain boundaries. It may be further



6 *Pronounced substructure developed at 750°C. A few recrystalliezd grains* (A, B, *and* C) *emerge with a substructure free matrix and heavily etched boundaries* ×150



7 *Ten recrystallized grains developed near the rupture surface at 650°C* ×150

inferred that the presence of a cohesive coating promotes the formation of sub-boundaries. In one set of specimens, substructure is developed much more pronouncedly in the coated strip than in the bare strip. This correlation is consistent with the theory that surface films may act as barriers to the motion of dislocations.[10] Since all specimens are coated in the second set, the difference in the creep-rupture behaviour between specimens must be due to some unrevealed factors such as defective bonding of the coating, etc.

Recrystallization During creep, Si–Fe may recrystallize locally either in regions of high strain, usually at the rupture surface; or in polygonized matrix. The recrystallized grains have a substructure-free matrix. Their boundaries are sharp as in the as-received condition and by no means zigzag. Figure 7 shows such recrystallized grains near the rupture surface. The lowest temperature at which this type of recrystallization can occur has been observed to be at 600°C. Starting from 700°C, recrystallized grains are nucleated at grain boundaries in polygonized matrix (Fig.6).

Grain coarsening Specimens ruptured at and above 800°C are characterized by a fully polygonized matrix, large grain size, and the emergence of many inclusions. The inclusions are originally contained in grain boundaries but left behind to be within grains after the boundaries have migrated. Because of the diminishing impeding effect of inclusions at high temperatures and a different driving force that is provided by the difference in sub-boundary energy per unit volume between grains,[6] the boundary migration is not restricted in extent nor in localities as in the confined boundary migration between 500° and 650°C. The extensive boundary migration causes the coarsening of the grains.

DISCUSSION

In a recent paper, Chen and Machlin[4] have shown an increase of ductility of Cu with rising temperature, owing to the effect of grain-boundary migration on void formation. In the present case, however, the increase of ductility from 550° to 800°C must be due to other reasons because extensive grain-boundary migration does not occur until 800°C.

The analysis of creep curves in Table I indicates that the increase of ϵ_{total} with temperature is largely due to a marked rise of ϵ_f. From its definition, ϵ_f may be expressed as follows:

$$\epsilon_f = \dot{\epsilon}_s . t_f + \int_{t_p}^{t_r} \Delta\dot{\epsilon} dt \quad \ldots\ldots (1)$$

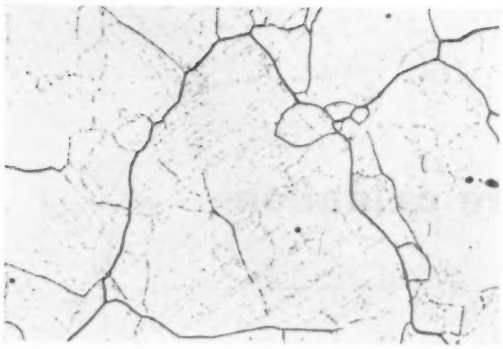
where $\Delta\dot{\epsilon}$ is the instantaneous tertiary creep rate, $\dot{\epsilon}_f$, minus $\dot{\epsilon}_s$ and t_r the rupture time. $\Delta\dot{\epsilon}$ is always positive as $\dot{\epsilon}_f$ is always greater than $\dot{\epsilon}_s$. The analysis further discloses two effects of temperature: the increase of $\dot{\epsilon}_s$ as a result of the thermally activated process of creep and the prolongation of t_f by an early termination of steady-state creep in a fixed rupture life.

According to Orowan[11] who assumes a constant yield stress to represent an invariant mechanical state for steady-state creep, $\dot{\epsilon}_s$ is defined as the ratio r/h, where r is the rate of recovery, $r = -\partial\sigma/\partial t$, and h the coefficient of strain-hardening, $h = \partial\sigma/\partial\epsilon$. An increase of r due to a softening process will not only bring steady-state creep to a prompt end, but also raise $\dot{\epsilon}_f$ steadily in excess of $\dot{\epsilon}_s$. Both terms of ϵ_f in equation (1) are thus promoted towards a large ϵ_f. Hence the large increase of ductility observed in Fig.2 may be attributed partly to the thermal effect on $\dot{\epsilon}_s$ and partly to a major structural change that is essentially a softening process.

Among the structural changes observed between 550° and 800°C, only polygonization deserves a careful

TABLE I Analysis of creep curves at 600°, 700°, and 800°C

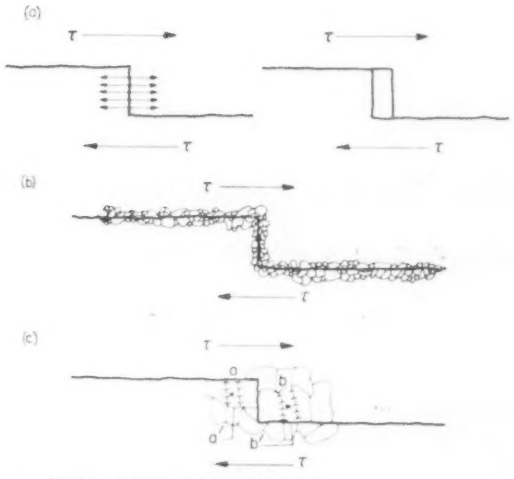
Temp., °C	σ_a, lb/in²	Pre-tertiary stage ϵ_p, %	Pre-tertiary stage t_p, h	Tertiary stage ϵ_f, %	Tertiary stage t_f, h	ϵ_{total}, %	$\dot{\epsilon}_s$, h⁻¹	Rupture time, h
600	6770	7·7	5·17	6·3	2·07	14·0	$1{\cdot}36\times10^{-2}$	7·24
700	3070	11·5	3·58	19·9	3·62	31·4	$3{\cdot}09\times10^{-2}$	7·20
800	1340	14·1	2·50	40·5	5·42	54·6	$4{\cdot}14\times10^{-2}$	7·92



8 *Slip lines produced under compression are resolved into arrays of dislocation pits which penetrate through sub-boundaries* ×250

examination because others are merely local phenomena. Beck[12] has reviewed various softening effects of polygonization in cold-worked metals. Although it has been suggested that polygonization may cause hardening,[13] the hypothesis has not yet been proved by a crucial experiment. Currently Li[14] has concluded in a theoretical analysis that a dislocation wall is not a very effective barrier to the penetration of dislocations. As seen in Fig.8, in no case has any avalanche of dislocations been held by a sub-boundary. The slip lines in this figure were produced at room temperature under compression in a sample previously ruptured at 700°C. It is likely that polygonization is mainly a softening process in Si–Fe. Hence the positive temperature coefficient of ductility may be partly ascribed to polygonization. This interpretation is in good agreement with the detailed development of substructure at various temperatures previously described.

The effect of sub-boundaries on void formation may be explained by two models illustrated in Fig.9. In the first model (Fig.9*b*), sub-boundaries support the grain boundary in resisting shear stress. It is also probable that the grain boundary *per se* is stronger because more jogs are introduced along the boundary. With such strengthening, grain-boundary sliding may be prevented or it occurs to a lesser degree. This model is particularly effective when the average size of subgrains is smaller than the spacing between successive jogs of grain boundaries. When subgrains grow to larger sizes, another model may replace the first one in subduing void formation. This second model (Fig.9*c*) is based on the hypothesis that sub-boundaries of the symmetrical tilt type may migrate under shear stress,[15] which will not activate Frank-Read sources in the vicinity. The migration of sub-boundaries will relieve the stress concentration induced at jogs by grain-boundary sliding. The effectiveness of the second model depends on the orientation of the sub-boundary relative to the induced stress. The most favourable geometry is that Burgers vector of the edge dislocations in the sub-boundary is in the direction of the induced stress. Although both models may operate at different creep stages, they exert the same minimizing effect on void formation.



a Void nucleation at a boundary jog
b The attachment of sub-boundaries strengthens the grain boundary in resisting boundary sliding
c The migration of favourably oriented sub-boundaries (aa' and bb') may effectively relieve the stress concentration induced around a jog by boundary sliding

9 *Models* (b *and* c) *illustrating two possible reasons why the development of substructure near grain boundaries minimizes the formation of intercrystalline voids*

Ductility associated with intercrystalline cracking is low (10–15% elongation) and temperature-independent. But ductility with necking-dominated rupture increases rapidly from 22% elongation at 600°C to a maximum value of 53–62% around 750°C. This increase of ductility has been ascribed partly to the thermally activated process of creep and partly to polygonization.

Visible voids are not found until the beginning of tertiary creep. Void formation may be minimized by the development of sub-boundaries at grain boundaries. Two models are proposed to account for the effect of sub-boundaries on void formation.

MgO surface coating increases the creep resistance and reduces the susceptibility of sheets to void formation.

SUMMARY

Necking, void formation at grain boundaries, and the development of paired edge cracks are three processes of rupture of 3·25%Si–Fe sheets above 550°C. Intercrystalline cracking is only prominent below 650°C. Necking dominates rupture at higher temperatures.

ACKNOWLEDGMENTS

The author wishes to thank Drs Wiener, Wiedersich, and Hu for their valuable comments.

REFERENCES

1. C. W. Chen: *Trans. AIME*, 1956, **206**, 1416–1417.
2. A. H. Sully and H. K. Hardy: *J. Inst. Metals*, 1953–54, **82**, 264–265.
3. H. C. Chang and N. J. Grant: *Trans. AIME*, 1956, **206**, 544–551.
4. C. W. Chen and E. S. Machlin: *ibid.*, 1960, **218**, 177–179.
5. A. S. Nemy and F. N. Rhines: *ibid.*, 1959, **215**, 992–998.
6. C. G. Dunn and F. W. Daniels: *ibid.*, 1951, **191**, 147–154.
7. J. N. Greenwood *et al.*: *Acta Met.*, 1954, **2**, 250–258.
8. D. Hull and D. E. Rimmer: *Phil. Mag.*, 1959, **4**, 673–687.
9. J. Intrater and E. S. Machlin: *Acta Met.*, 1959, **7**, 140–142.
10. C. S. Barrett: *ibid.*, 1953, **1**, 2–7.
11. E. Orowan: *Trans. Inst. Eng. Ship. Scotland*, 1946, **89**, 165–215.
12. P. A. Beck: *Advan. Phys.*, 1954, **3**, 245–324.
13. C. H. Li *et al.*: *Trans. AIME*, 1953, **197**, 1223–1225.
14. J. C. M. Li: *Acta Met.*, 1960, **8**, 296–311.
15. W. T. Read: 'Dislocations in metals', Ch.2, 1954, 66, AIME.

An X-ray high-temperature oxidation study on iron–copper

H. J. Goldschmidt, D.Sc., F.Inst.P.

SYNOPSIS

The X-ray high-temperature camera method can serve as a useful tool to follow the oxidation sequences on metals, and this is demonstrated on iron–copper mixed powder compacts. The results show the types and proportions of pure metal and oxide phases during oxidation as a function of time and temperature up to 1000°C at a low air pressure. A major feature is a radical change in oxide constitution on passing the A_3 point in Fe, *accompanied by the reappearance of the metal phases, and suggesting a recovery in protectiveness.*

The merits and limitations of the method are briefly discussed. 1873

INTRODUCTION

THE OBJECT of this short paper is two-fold: first to show that, as a technique for studying oxidation kinetics at high temperatures, X-ray high-temperature powder photography can prove a useful tool, and second, to demonstrate this by results so obtained on compacts of iron and copper powder mixtures. The X-ray and electron-diffraction methods for constitutional studies on the oxidation of metals are of course well established: however, this approach has generally been limited to work at room temperature on oxides previously produced at high temperatures, rather than on oxides while forming *in situ* at temperature (except for the electron diffraction work on the oxide films in formation, for instance by Jackson and Quarrell,[1] Germer,[2] and Gulbransen and Hickman.[3])

The use of iron and copper as the paired metals in this study offers (apart from its inherent interest) a fundamental point of attraction: the affinities for oxygen of Fe and Cu differ widely, yet not so widely that oxidation of the nobler metal is excluded; furthermore, the Fe–Cu system shown in Fig.1, is essentially two-phase, so that mutual diffusion of the metals remains insignificant (in contrast for instance to an intersoluble Fe–Ni or Fe–Co pair), and no intermetallic compound occurs (in contrast to so many other iron/second metal pairs). Therefore, the reaction system of the two metals *vis-à-vis* oxygen is simplified, and contact between the two primary metals can be maintained, without confusing the issue by mutual alloying. That Fe and Cu are both transition metals of the same long period and of similar atomic size, is a further simplifying factor.

EXPERIMENTAL

The high-temperature X-ray diffraction camera used was that designed and built at these laboratories and described previously.[4] In the present instance evacuation was continuous, but a residual air pressure of 0·5 μ Hg was maintained, sufficient to permit a limited degree of oxidation.

The samples consisted of intimate mixtures of high purity iron and copper powders of particle size 20–40 μ compacted to thin rods 1 mm in dia. in a special die under a pressure of 60 tons/in^2. The proportions were 50%Fe: 50%Cu (at-%). These rods were used as X-ray specimens directly.

Temperature/time sequences of exposures in the high-temperature camera were as follows:

Temperatures	530°, 620°, 720°, 810°, 905°, 1000°C, each maintained for 7 h
Times	0–1, 2–3, 4–5, 6–7 h at each temperature.

The 1 h intervals between the (1 h) exposures permitted oxidation to advance, so that, as it were, an intermittent 'cine' sequence of oxidation was obtained. A new sample was used for each temperature. The radiation used was cobalt K_α and phase identification and measurement of amounts were carried out by normal methods of powder photography. The temperature was measured by a platinum/platinum–rhodium thermocouple to an accuracy of the order of ±2°C, using a method of calibration previously described.[5] Cobalt K_α radiation was used, and identification and measurement of amounts of phases were carried out by normal methods of powder photography, from the known diffraction patterns of the phases concerned: visual comparison with standard mixtures, as well as of the test photographs with each other facilitated the quantitative determination. The absolute accuracy was within about 10% of the total amount given, but the relative accuracy of values (on which the main emphasis should be laid in considering the present results) was appreciably higher.

IRON AND COPPER OXIDES

The binary oxide systems Fe–O and Cu–O are well established, and a reference to the literature will

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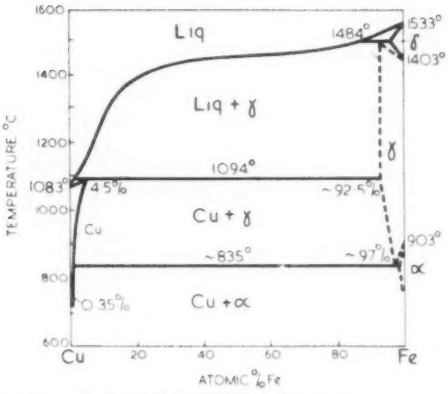
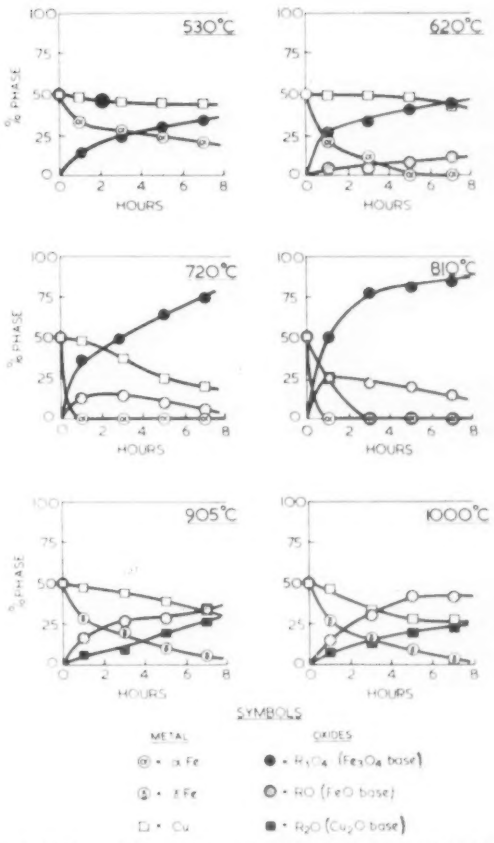


1 *Iron–copper phase diagram (after Hansen)*



2 *Oxidation of* Cu–Fe *compacts (50/50) as observed in high-temperature X-ray camera (phase types and amounts, function of temperature and time, air pressure 0·5 μ)*

suffice (e.g. see phase diagrams in Hansen[6] pp.605 and 686). No ternary oxides of iron and copper exist; however, a partial solid solubility of Cu in FeO and in spinel Fe_3O_4, tending towards a spinel Fe_2CuO_4, is very probable and the latter compound is known.[7]

Table I summarizes, for reference, the known data on iron and copper oxides relevant in this connexion. The structural relations of Fe, and of FeO and Fe_3O_4 formed on iron have been discussed in an earlier paper.[8]

RESULTS

The results of the present investigation, in terms of types and amounts of phases, are shown in Fig.2.

The following phases appeared: Iron in its α and γ forms; copper; and the lower oxides wüstite, magnetite, and cuprite; in no case has oxidation progressed to the free ferric or cupric oxides, although, of course, Fe_3O_4 contains some ferric ions (the higher oxides being in any case unstable above about 850°C at the low pressures concerned).

The curves in Fig.2 give a great variety of detailed information, which is instructive, not only because consistent with known phase-relationships, but also in revealing, it is believed, several novel features. Figure 3 shows the overall amounts of oxide as against metal, ignoring the type of oxide.

DISCUSSION AND CONCLUSIONS

The rate of oxidation, as is to be expected, differs widely between the Fe and Cu components: at 530° and 620°C, the proportion of free copper remains substantially unchanged, while that of free iron decreases rapidly.

The oxide formed at 530°C is spinel only, but from 620°C upwards wüstite also occurs; this is in accord with the known fact of the wüstite eutectoid in the Fe–O system occurring at 570°C.

The rate of decrease in free iron through oxidation increases with temperature, up to the A_3 point. This iron loss has become immediate at 720°C, where copper also begins to be attacked appreciably, though more slowly; Fe_3O_4 increases to large amounts, but FeO remains subsidiary, even somewhat decreasing

TABLE I Details concerning the pure iron and copper oxides

Compound	Structure	Lattice spacings, Å	Melting point and stability and melting point, °C	Heat of formation at 25°C (kcal/mole)
Wüstite 'FeO'	NaCl type (defect lattice, Fe-deficient)	a = 4·277 to 4·311	1371 (Eutectoid decomposition to Fe + Fe_3O_4 at 570°C)	645
Magnetite Fe_3O_4	Cubic, Spinel type	a = 8·374 (Fe, Cu) O.Fe_2O_3: 8·445	1597 Stable throughout	267
Hematite Fe_2O_3 (α-form)	Rhombohedral, Corundum type (γFe_2O_3 = Spinel)	a = 5·414, α = 55° 17′	1457 Stable throughout	195
Cuprite Cu_2O	Cubic, Cu_2O type	a = 4·252	1230 (Eutectoid decomposition to Cu + CuO at 375°C)	41
Tenorite CuO	Monoclinic	a = 4·653, b = 3·410, c = 5·108, β = 99° 29′	(Decomposes rapidly to $Cu_2O + O_2$ at high temperatures)	375

after a maximum, in favour of Fe_3O_4. Similar behaviour recurs at 810°C, except for the quantitative differences shown in Fig.2.

However, radical changes in behaviour occur on passing from the 810° to the 905°C series, clearly associated with the $\alpha \rightarrow \gamma$ transformation (A_3 point) in iron (*see* Fig.1). These changes are: (*a*) free iron is now again present, in its γ form, revealing, it is suggested, a greater inherent oxidation resistance than the preceding α form. The presence of free copper is also largely restored, but this has another reason (*see* below). (*b*) Fe_3O_4 (spinel) disappears abruptly and entirely. The oxides now formed are the lower ones, of FeO and (for the first time) of Cu_2O base. It is significant to point out that they are those oxides which in crystal structure are closely related to the face-centred cubic ones of γ–Fe and Cu (in FeO of course, the metal-ion lattice is identical with the atomic one in γ–Fe and Cu, and a degree of protectiveness seems to be afforded by both the FeO and Cu_2O layers).

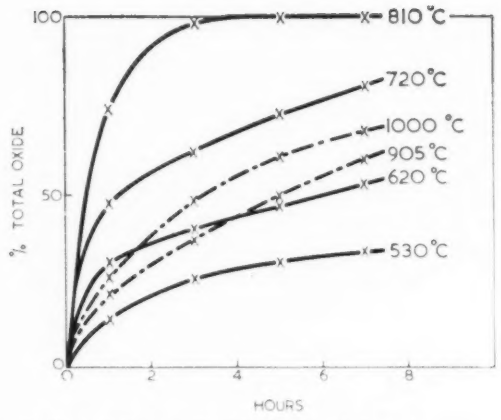
The amount of FeO now steadily increases with time in contrast to the previous decrease; however this is probably explained simply by the elimination of Fe_3O_4 formation.

At 1000°C (*see* Fig.2) the picture is similar to that at 905°C, except for quantitative differences, mainly an increase in FeO.

The test temperature of 905°C (±2°C) is close to the A_3 point, variously reported as between 900 and 910°C in pure iron, but lowered by a slight copper solution (eutectoid probably at 835°C and 3 at-%Cu, *see* Fig.1).

It would thus appear that the sudden increase in protectiveness is associated with the presence of the simple $(R^{++})O$ and $(R^{+})_2O$ type oxide films rather than spinel $(R^{++})O.(R^{+++})_2O_3$, and that this in turn is due to the greater dimensional compatibility with the cubic close-packed base lattices of γ–Fe and Cu. Furthermore, the formation by copper of its own primary oxide, Cu_2O, would thus act more protectively than the previous spinel, which was iron-based with copper only as a minor solute; the latter, unlike Cu_2O, would not be able to form a coherent lattice with copper, leaving it exposed to attack as at 810°C. It might thus be said that the coexistence of α–Fe, in close intermixture, has detracted from the oxidation resistance of copper, but that this is remedied upon transformation to γ–Fe, permitting Cu_2O to develop. The lattice contraction during the $\alpha \rightarrow \gamma$ change may also have contributed to this effect, since the atomic volumes and coefficients of expansion of Cu are more commensurate with γ–Fe than with α–Fe.

It must be remembered, in considering the results, that by X-ray diffraction we encompass of course only a surface layer of the specimen, which in the present instance was of a thickness of the order of 0·1 mm. Therefore the 'absence' of a phase will only apply to this depth of penetration, and the core of the specimen will still have contained free metal throughout. Also it is known[8, 9] that scale layers upon iron generally follow in sequence $FeO \rightarrow Fe_3O_4 \rightarrow Fe_2O_3$ from metal/oxide to oxide/gas interface. In the present case the oxide coat, even in the severest case, remained sufficiently thin to observe all phases within it; however, the magnetite layer may partly have masked some underlying wüstite in intensity, and this may imply a certain quantitative underestimate of the latter in Fig.2; but that this correction is only minor, may be seen by the genuine absence of wüstite at 530°C, where the magnetite layer was in fact thinnest. Any hematite, Fe_2O_3, at the outside would certainly have shown, and its absence must be attributed to the low pressure conditions, which, at the higher temperatures, would render the phase unstable, and at the lower ones would permit the relative rate of diffusion of iron and oxygen ions to be sufficient to maintain metal saturation. (γ–Fe_2O_3 of course also possesses the spinel structure; however, its formation under present circumstances is highly unlikely; in fact Gulbransen and Hickman[3] have shown by electron diffraction that it only forms on iron below about 200°C. Nevertheless, the tendency of the Fe and Cu oxides to dissolve oxygen and become defect lattice semiconductors is important, and the oxygen gradient will vary with pressure.) The same applies to cupric oxide CuO, which is unstable above about 600°C at the pressures concerned.



3 Fe–Cu *oxidation, as Fig.2 but total oxide formed*

It has long been used as a criterion of protective-layer formation upon metals that a parabolic rather than a linear weight increase/time law holds good:[10] the linear law reflecting the formation of cracks and continuous oxygen→metal access, the parabolic one that of a coherent film. For iron, the position is complicated by the multiple oxide structures formed, although the law $\Delta W^2 = KT + C$ (ΔW=weight increase, T=temperature, K, C=constants) have been found valid with fair approximation.[11] It would not appear justified to try interpreting the present results in these terms without caution and several corrections; but the total-oxide/time plot in Fig.3 nevertheless suggests an initially parabolic law, becoming linear in time. It certainly demonstrates the steady overall increase with temperature within the ferritic region, and the recovery as the austenitic region is entered (with the more specific breakdown given in Fig.2).

It might be tempting to suggest the use of X-ray high-temperature powder photography as an alternative means of oxidation measurement on metals *in situ* in the camera, with the added attraction that only a much smaller sample would be required than in conventional oxidation testing, and of simultaneous disclosure of phase formation. Absorption errors, the occurrence of phase-changes and other physical variables would, it is believed, always detract from quantitative precision. Nevertheless, much basic information can already be obtained by studies of the

above type, and under standardized conditions in a set problem, the method can vary and possibly be developed to serve as one of simple quantitative routine oxidation analysis.

While room temperature X-ray examination of samples subsequent to high-temperature oxidation is already valuable, phase-changes upon cooling are likely to occur (for example, oxide films which are FeO at high temperatures can convert to Fe_3O_4 on cooling)[1] so that the need for high-temperature examination exists.

ACKNOWLEDGMENT

The author wishes to express his thanks to Mr Oliver, C.B.E., Director of Research, The BSA Group Research Centre, for his interest and encouragement.

REFERENCES

1. R. Jackson and A. G. Quarrell: *ISI Spec. Rep. no.24*, 1939, 65.
2. L. H. Germer: *Phys. Rev.*, 1937, **52,** 959–967.
3. E. A. Gulbransen and J. W. Hickman: AIME Tech. Publ., 1946, nos.2068, 2069.
4. H. J. Goldschmidt and J. Cunningham: *J. Sci. Inst.*, 1950, **27,** 177–182; H. J. Goldschmidt: 'X-ray diffraction by polycrystalline materials', Ch.9, 1955, London, The Institute of Physics.
5. J. A. Brand and H. J. Goldschmidt: *J. Sci. Inst.*, 1956 **33,** 41–45.
6. M. Hansen: 'Constitutions of binary alloys', 1958, McGraw-Hill, New York.
7. L. Weil *et al.*: *J. Phys. Radium*, 1950, **11,** 208.
   F. Bertaut and C. Delorme: *Compt. Rend.*, 1954, **239,** 504–505.
8. H. J. Goldschmidt: *JISI*, 1942, **146,** 157–180.
9. L. B. Pfeil: *ibid.*, 1929, **119,** 501–560 and 1931, **123,** 237–258.
   A. Michel *et al.*: *Bull. Soc. Chim. France*, 1943, **10,** 1.
   J. Benard and O. Coquelle: *Compt. Rend.*, 1946, **222,** 796–797.
10. N. B. Pilling and R. E. Bedworth: *J. Inst. Metals*, 1923, **297,** 529–591.
11. A. Portevin *et al.*: *Rev. Met. (Bucarest)*, 1934, **31,** 101, 186, 219–236.

ANDREW CARNEGIE RESEARCH REPORT

The kinetics of sulphur transfer from iron to slag

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INTRODUCTION

During the last 10–15 years considerable interest has been focused on the problem of sulphur removal from iron and steel. To permit the maximum efficiency of removal in industrial processes it is important that the reactions involved in the sulphur transfer between the metal and the slag should be fully understood and, to this end, a number of investigations have been reported.[1–14] From these results, the influence of variables such as temperature and slag composition are fairly well known, but the actual mechanism of the reaction and therefore the so-called 'slow-stage' in the process, is still in doubt.

For a full understanding of the kinetics of the reaction it is important that the sulphur transfer be investigated over a wide range of slag compositions and temperature. Previous workers have tended to confine their investigations to relatively small changes in either one or the other of the variables so that only a limited analysis is possible and it is not reliable to combine results from different investigators since the experimental conditions, e.g. geometry of the reaction crucible, can profoundly affect the progress of sulphur transfer.

The present work was therefore planned to measure the sulphur transfer rate using a wide range of slag compositions and temperatures, covering most of the conditions met in the blast-furnace. The influence of metal composition has not been studied.

Manuscript received 26 July 1960.
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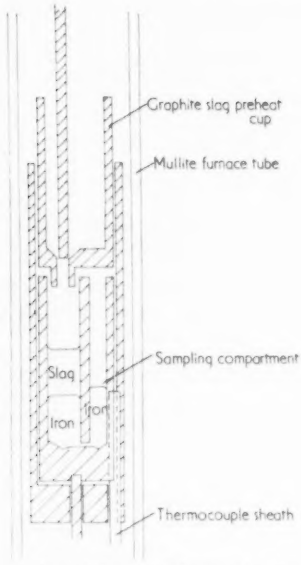
SYNOPSIS

The transfer rate of sulphur from carbon saturated iron to a range of $CaO–MgO–SiO_2–Al_2O_3–CaF_2$ *slags has been investigated on a laboratory scale at temperatures between 1400° and 1600°C. Analysis of results shows that sulphur transfer is a thermally activated process and that the rate limiting step is probably of a chemical nature associated with the breaking of metal–oxygen bonds in pure oxide slags. The addition of* CaF_2 *results in an increase in the transfer rate due to a change in the transfer mechanism. The application of these results to iron and steelmaking processes is discussed.* 1822



1 *Arrangement of retaining crucible, reaction crucible, and slag holder within the furnace*

MATERIALS

A 20 lb batch of iron was obtained by melting soft steel scrap in an induction furnace and gradually adding charcoal after skimming off the oxidized slag, until the iron was carbon saturated. The iron charges for the subsequent experiments were taken from this batch. The addition of the radioactive isotope S^{35} is described in the Appendix.

The slags were prepared from pure oxides MgO, Al_2O_3, SiO_2, precipitated chalk $CaCO_3$, and CaF_2 powders. The powder was thoroughly mixed by rotation in a slow-running lathe for several hours and then melted under an electric arc.[15] Sufficient slag of each composition was prepared for several experiments. Slags prepared in this way picked up a negligible quantity of carbon in the transfer experiments.

APPARATUS AND PROCEDURE

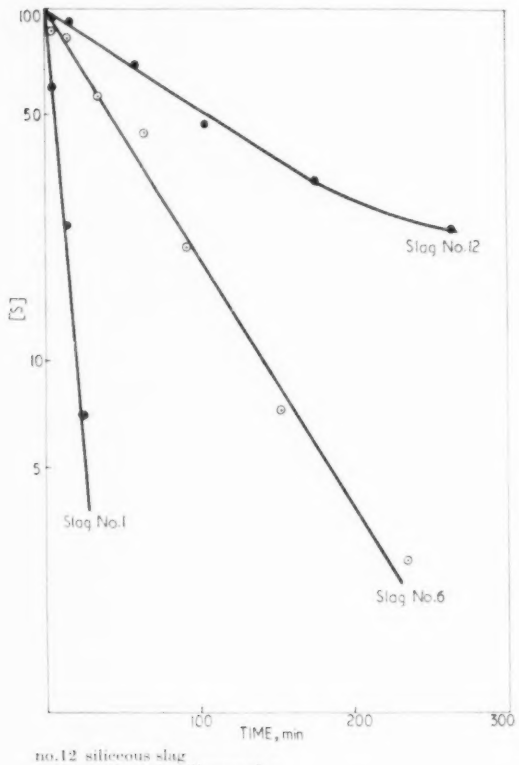
In each experiment 145 g iron and 15 g iron master alloy containing radioactive sulphur were melted in a twin cavity graphite crucible held in a molybdenum wire wound furnace (Fig.1). A nitrogen atmosphere was maintained in the working tube to prevent oxidation of the graphite. The crucibles were prepared by drilling two vertical holes 5 in. deep in a 2 in. dia. graphite block and putting the holes into communication at the bottom. The larger cavity (1 in. dia.) served as the main crucible for the iron and slag, and the smaller cavity (0·45 in. dia.) was used as a sampling hole from which metal could be sucked into a silica tube without contamination by the slag. A copper rod inside the silica tube controlled the length of the sample.

TABLE I S and Si contents of iron

												k_M
Slag no.1	62%CaO 30%Al_2O_3 8%SiO_2											
1398°C	t.min	0	18	63	100	173	247	325				
	S	1000	825	268	131	26	...	...				0·0066
1470°C	t.min	0	9	20	40	64						
	S	1000	574	250	77	33						0·021
1505°C	t.min	0	5	14	23							
	S	1000	596	240	69							0·032
Slag no.2	31%CaO 31%MgO 29%Al_2O_3 9%SiO_2											
1400°C	t.min	0	11	60	113	183	258					
	S	1000	927	476	278	165	80					0·0040
1474°C	t.min	0	8	28	57	173						
	S	1000	765	406	247	40						0·011
	Si	...	...	0·12	...	0·16						
1550°C	t.min	0	16	35	77	148						
	S	1000	226	85	37	...						0·033
	Si	...	...	0·12	...	0·04						
Slag no.3	49%CaO 14%MgO 19%Al_2O_3 17%SiO_2											
1442°C	t.min	0	10	35	69	135	224	376				
	S	1000	770	538	280	36	18	24				0·0055
	Si	...	0·05	...	0·05	0·04	0·06	...				
1498°C	t.min	0	7	23	60	117	199	321				
	S	1000	745	370	115	70	14	9				0·014
	Si	...	0·07	...	0·07	0·06	0·07	...				
1556°C	t.min	0	6	16	36	68	136	231	352			
	S	1000	691	570	454	361	196	98	47			0·026
	Si	...	0·08	...	0·09	0·11	0·10	...	...			
Slag no.4	37%CaO 16%MgO 9%Al_2O_3 38%SiO_2											
1455°C	t.min	0	12	35	63	110	196	313				
	S	1000	960	880	725	565	396	240				0·0013
1500°C	t.min	0	4	15	33	60	105	197	472			
	S	1000	1000	958	803	658	492	265	102			0·0022
1600°C	t.min	0	20	54	90	127	169					
	S	1000	769	388	214	112	29					0·0054
Slag no.6	40%CaO 17%MgO 3%Al_2O_3 40%SiO_2											
1417°C	t.min	0	11	34	86	120	154	237	526			
	S	1000	870	778	340	281	174	91	34			0·0039
	Si	...	0·09	...	0·09	...	0·11	0·14	...			
1502°C	t.min	0	4	15	33	63	91	151	234	502		
	S	1000	860	825	568	448	208	72	27	33		0·0071
	Si	...	0·06	...	0·07	...	0·12	0·10	...	...		
1570°C	t.min	0	3	14	34	53	82	138	203	304	557	
	S	1000	983	875	764	722	285	108	43	40	35	0·011
	Si	...	0·07	...	0·08	0·10	...	...	...	...	...	

TABLE I (*continued*) **S and Si contents of iron**

											k_M
Slag no.8	28%CaO 27%MgO 6%Al_2O_3 39%SiO_2										
1440°C	t.min	0	10	30	63	121	224	313	448		
	S	1000	918	662	523	366	220	194	187		0·0039
	Si	0·06	...	0·06	0·06	0·191	0·35	0·43	0·68		
1510°C	t.min	0	8	23	55	127	237	339	513		
	S	1000	851	730	479	271	151	156	125		0·0051
	Si	0·09	0·09	...	0·13	0·28	0·44	0·67	1·07		
1570°C	t.min	0	6	16	37	70	134	227	566		
	S	1000	935	720	378	220	122	85	43		0·0081
	Si	0·03	0·03	0·04	0·14	0·26	0·45	0·80	1·62		
Slag no.9	43·5%CaO 9·5%MgO 6%Al_2O_3 41%SiO_2										
1400°C	t.min	0	10	58	102	186	256	385			
	S	1000	915	556	466	290	226	200			0·0034
	Si	...	...	0·12	0·20	0·26	...	0·51			
1500°C	t.min	0	5	13	38	78	141	192			
	S	1000	964	791	483	...	172	103			0·0066
	Si	...	...	...	0·12	0·24	0·38	0·50			
1600°C	t.min	0	11	29	62	89	130	181	341		
	S	1000	626	378	140	86	74	79	...		0·010
	Si	0·26	0·22	...	0·41	...	0·65	...	1·17		
Slag no.10	40%CaO 17%MgO 43%SiO_2										
1430°C	t.min	0	13	34	74	113	160	226	290		
	S	1000	850	695	512	534	356	214	240		0·0029
1500°C	t.min	0	7	15	30	48	81	136			
	S	1000	1020	940	781	649	400	118			0·0042
1560°C	t.min	0	5	13	29	56	151				
	S	1000	961	805	548	265	113				0·0069
Slag no.11	43·5%CaO 9·5%MgO 47%SiO_2										
1430°C	t.min	0	50	99	161	227	302				
	S	1000	472	278	193	164	150				0·0049
	Si	...	0·14	0·19	0·21	0·23	...				
1475°C	t.min	0	11	46	69	132	201	279	378	466	
	S	1000	932	378	257	105	105	83	75	57	0·0083
	Si	...	0·11	0·09	0·23	0·19	...	...	...	...	
1530°C	t.min	0	9	22	66	102	169	231			
	S	1000	537	234	124	37	39	7			0·019
	Si	...	0·29	0·22	0·46	0·66	...	...			
Slag no.12	37%CaO 9·5%MgO 6%Al_2O_3 47·5%SiO_2										
1396°C	t.min	0	24	69	113	190	261	321			
	S	1000	970	908	920	850	741	658			0·00026
1505°C	t.min	0	5	17	57	103	173	263	389		
	S	1000	950	922	705	472	327	236	177		0·0019
	Si	...	0·18	...	0·28	...	0·44	0·63	0·88		
1560°C	t.min	0	10	28	54	117	221	351			
	S	1000	976	892	517	270	169	139			0·0068
Slag no.13	27%CaO 9·5%MgO 6%Al_2O_3 57%SiO_2										
1400°C	t.min	0	24	73	116	192	279	364			
	S	1000	1002	956	937	948	920	...			0·00012
1470°C	t.min	0	15	42	86	158	250	388	527		
	S	1000	896	920	880	684	555	298	316		0·00071
1600°C	t.min	0	17	42	122	203	377				
	S	1000	950	561	158	57	...				0·0066
	Si	0	0·09	0·56	...	0·64	0·67				
Slag no.14	15%CaO 3%MgO 10%Al_2O_3 72%SiO_2										
1440°C	t.min	0	13	45	103	195	314	493			
	S	1000	951	955	943	981	958	951			0·000024
	Si	...	0·12	...	0·17	...	0·17	0·20			
1500°C	t.min	0	11	34	78	159	255	370			
	S	1000	971	982	982	975	940	828			0·000074
	Si	...	0·09	...	0·12	0·16	0·18	...			
1560°C	t.min	0	8	25	55	105	185	312	462		
	S	1000	968	968	935	890	838	791	692		0·00024
	Si	...	0·09	...	0·14	0·22	0·32	...	...		
Slag no.15	(49%CaO 14%MgO 19%Al_2O_3 17%SiO_2)+CaF_2										
1440°C	t.min	0	6	14	35	56					
	S	1000	525	302	151	115					0·038
1503°C	t.min	0	7	18	32	61					
	S	1000	277	144	...	101					0·056
1577°C	t.min	0	5	15	31	62					
	S	1000	304	65	55	50					0·085
Slag no.16	(42%CaO 10%MgO 48%SiO_2)+CaF_2										
1460°C	t.min	0	8	20	46	77					
	S	1000	855	756	665	422					0·0031
	Si	0·78	0·102	...	0·10	0·158					
1485°C	t.min	0	5	15	33	72					
	S	1000	864	740	586	321					0·0060
	Si	0·04	0·05	0·07	0·08	0·18					
1510°C	t.min	0	3	13	29	53	80				
	S	1000	898	755	551	352	262				0·0059
	Si	...	0·02	0·06	0·08	0·14	0·20				
1565°C	t.min	0	5	11	21	42	80				
	S	1000	900	850	675	457	219				0·0059
	Si	...	...	...	0·07	0·14	0·26				
Slag no.17	(37%CaO 9·5%MgO 6%Al_2O_3 47·5%SiO_2)+CaF_2										
1420°C	t.min	0	7	24	52	83	123				
	S	1000	981	949	890	(740)	(510)				0·00068
1505°C	t.min	0	5	15	37	67	97				
	S	1000	950	861	465	(446)	(377)				0·0029
1570°C	t.min	0	6	17	35	60	96				
	S	1000	845	655	408	248	204				0·0078



no.12 siliceous slag
no.6 moderately siliceous slag
no.1 aluminous slag

2 *Desulphurization curves log* [S] v *time*

To ensure that the iron samples were representative of the iron in the main cavity, a close-fitting graphite plunger was used to displace the iron from the sampling hole except when a sample was required. When the furnace temperature was steady at the desired value, an iron sample was removed, and then 45 g of prefused slag was added. Whenever practicable a graphite slag cup situated above the reaction crucible was used (Fig.1) to allow addition of molten slag, but in a number of experiments the 'fluid temperature' of the slag was higher than that obtaining in this relatively cool part of the furnace and in these cases solid pieces of slag were dropped on to the molten iron.

The 'zero-time' was taken as the time when the stopper was removed from the slag cup or when the solid pieces of slag had melted, usually after 2–4 min. Further samples of iron were taken at intervals throughout the experiment.

The change in sulphur content of the successive iron samples from each experiment was followed by counting the soft (0·167 MeV) β-emissions of S^{35} using an end-window Geiger–Müller tube; these counting rates are proportional to the sulphur content of the specimens and hence can be converted into weight percentages by making a chemical analysis for sulphur of the first high sulphur content sample. The roughly cylindrical specimens were ground flat on their end surfaces and these surfaces were held in a fixed position under the end window of the Geiger–Müller tube, by a jig. The grinding operation was carried out under water in a specially constructed apparatus to avoid the spread of radioactivity. This method of counting solid samples is to be preferred to the more usual method of counting crushed samples since it reduces to a minimum the serious health hazard attendant upon radioactive dust.

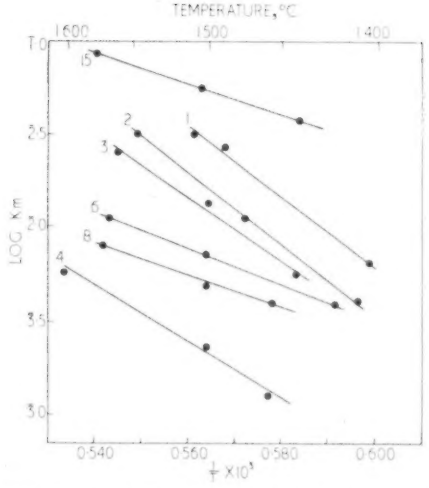
RESULTS

For convenience of reference, the experiments are grouped together according to the slag composition, and the slag identification numbers have been arranged so that slag no.1 is the most basic and higher numbers roughly correspond to higher acidity up to slag no.14. Slags nos.15, 16, and 17 illustrate the effects of calcium fluoride additions to oxide slags.

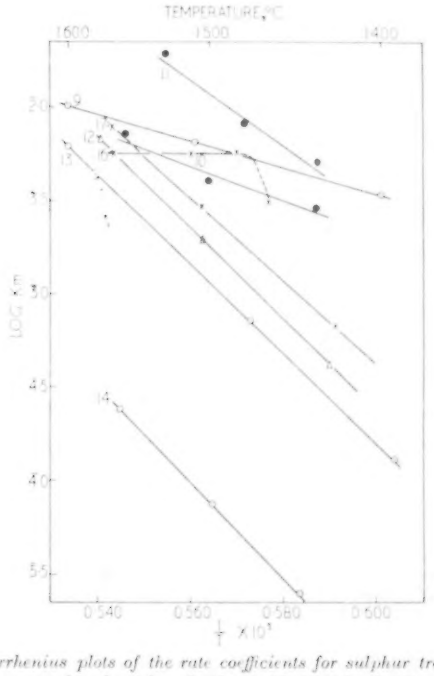
The values of the sulphur concentrations in iron (*see* Table I) have been rationalized to an initial concentration of 10^3 to allow immediate comparison of the results for different temperatures and slags. The average concentration of sulphur in the iron before addition of the slag was 0·16 wt-%. A number of the samples were large enough (2 g) for chemical analysis to determine the silicon content of the iron and these results are given in Table I. However, the values in many cases, particularly the more basic slags, are small and, in view of the small sample weights, are best considered as a qualitative indication of the rate of slag–silica reduction. The prefused slags were chemically analysed by fusion with sodium carbonate and extraction of the fused mass in acid. Subsequent analysis followed the standard gravimetric methods. The analysed compositions of the slags are also given in Table I and temperatures are estimated to be within ±10°C of the stated value.

Most of these slags presented no particular difficulties, but a few behaved in an abnormal way. Slag no.6 had a fairly high liquidus temperature (about 1390°C) and could not be premelted in the slag crucible (Fig.1) even for the experiment at 1570°C. It was therefore dropped on the liquid iron as solid pieces and the finite time required for complete fusion is probably the reason for the initial slow transfer rate. However, the later samples indicate the true rate and this has been used for comparison with other slags. At lower temperatures (1417° and 1500°C) this 'incubation time' is not so apparent since the true rates were relatively slow and the differences between the initial and true rates were not so pronounced.

Slags nos.12, 13, and 14 are highly siliceous and tend to have a long softening range, i.e. a large temperature difference between the solidus and liquidus, and to be viscous, particularly in the early stages of melting. In the high temperature (1560°C) experiments it was observed that the slag was 'lifted' by bubbles of CO. After a few minutes the melt quietened down and the removal of sulphur proceeded at a fairly rapid rate. It is likely that the gas film between slag and metal in the early stages of transfer, due to the high viscosity of the slag, inhibited sulphur transfer giving rise to the 'incubation periods' in slags nos.12, 13, and 14. At temperatures below 1500°C, the evolution rate of CO was probably too slow to form an interface gas film. The fluoride-bearing slags, nos. 15, 16, and 17 all contained an addition of 4·5 wt-% of CaF_2. Of these, slag no.16 had a fairly high liquidus temperature (about 1450°C) and it is significant that the rate of sulphur transfer at 1460°C is considerably lower than would be expected from consideration of the three higher



3 *Arrhenius plots of the rate coefficients for sulphur transfer from metal to slag (slags 1, 2, 3, 4, 6, 8, 15)*



4 *Arrhenius plots of the rate coefficients for sulphur transfer from metal to slag (slags 9, 10, 11, 12, 13, 14, 16, 17)*

temperature experiments. This illustrates the importance of exceeding the liquidus temperature of a slag by 30–40°C if the variation with temperature of the slag properties is to be determined by measurement at a limited number of temperatures.

Slag no.16 is equivalent to slag no.12+CaF_2 and during experiments with this slag at 1420°C and 1505°C only the first four samples are reliable, owing to difficulties in temperature control; these clearly defined the rate of the reaction and reliable values for the rate coefficient were obtained.

DISCUSSION

Factors governing sulphur transfer

By analogy with other mass transfer processes, the sulphur transfer between liquid iron and liquid slag should be dependent on four main factors:

(i) concentrations of sulphur in the iron and slag
(ii) area of the iron/slag interface
(iii) temperature
(iv) composition of the iron and slag with regard to components other than sulphur, e.g. Si and SiO_2.

If factors (ii), (iii), and (iv) are kept constant as was done as far as possible in the experiments, then the mass transfer is related to the sulphur concentrations according to

$$-\frac{d[S]}{dt}\frac{W_M}{100\,Z}=k_M[S]^m-k_S(S)^n \quad \ldots\ldots(1)$$

where [S] and (S) are the concentrations of sulphur in metal and slag respectively, wt-%; k_M and k_S are the rate coefficients of sulphur transfer from metal to slag and from slag to metal respectively, g cm^{-2} min^{-1}; W is the mass of metal, g; Z is the area of the slag/metal interface, cm^{-2}; and m and n are the orders of the forward and reverse transfer reactions. At the beginning of a transfer experiment, (S) is zero and the above equation simplifies to

$$-\frac{-d[S]}{dt}=\frac{100\,Z}{W}\,k_M\,[S]^m \quad \ldots\ldots(2)$$

If the equation is first order, i.e. $m=1$, equation (2) may be integrated to give:

$$\log [S]_{t=0}-\log [S]=-\left(\frac{100\,Z\,k_M t}{2{\cdot}303\,W}\right)_{t\to 0} \quad \ldots\ldots(3)$$

The assumption of first order kinetics above, is justified by the initially linear slope of desulphurization curves when plotted as the logarithm of the metal sulphur content versus time, as required by equation (3); examples of desulphurization data plotted in this way for highly siliceous, moderately siliceous, and aluminous slags are given in Fig.2. In most experiments these semilogarithmic plots were linear up to at least 100 min and the value of the rate coefficient k_M was determined from the initial slope of each plot, using equation (3). The accuracy of individual k_M values determined in this way is estimated to be $\pm 3\%$.

Values of k_M calculated from semilogarithmic plots for all experiments are given in Table I. Values of k_S, the mass transfer coefficient for sulphur transfer from slag to metal, cannot be obtained accurately by analysis of the experimental desulphurization curves since the k_S values so obtained have the same absolute error as k_M but have a magnitude of $10^{-2}\times k_M$. It should be emphasized that the k_M values obtained by this method are for the initial conditions and thus apply to the transfer of sulphur from pure carbon-saturated iron; experiments by other workers[4,9–11] have indicated that additions of other elements to the iron markedly influence the value of k_M.

If the process of sulphur transfer is thermally activated, the rate coefficients should obey the Arrhenius relation for such rate processes, i.e.

$$k_M=A\exp(-E/RT) \quad \ldots\ldots(4)$$

where A is the frequency factor, g cm^{-2} min^{-1}; E_a is the experimental activation energy for the process,

TABLE II Derived values of the activation energy E_S (kcal, g mol^{-1}) and the frequency factor A (g cm^{-2} min^{-1}) for sulphur transfer from metal to slag

Slag no.	E_s	log$_e$ A
1	89	22·7
2	89	22·7
3	80	18·4
4	63	12·5
6	37	5·9
8	41	7·0
9	32	4·3
10	42	7·2
11	86	20·1
12	114	25·9
13	114	25·9
14	119	24·8
15	36	7·8
16	0	−4·1
17	103	25·3

kcal/g mol; R is the gas constant (1·98 cal °C^{-1} mol^{-1}; and T is the absolute temperature, °K. On taking logarithms, equation (4) becomes:

$$\log k_M = \log A - \frac{E_s}{2{\cdot}303\,RT} \quad \ldots\ldots(5)$$

Plots of the logarithm of the rate coefficients in Table I versus $1/T$ are shown in Figs.3 and 4; these are clearly linear obeying equation (5) showing that sulphur transfer is a thermally activated process. Values of the activation energy E_s and frequency factor A obtained from these plots are given in Table II. The errors in E_s and log A are estimated to be ±5 kcal/g mol and ±5% respectively. Knowledge of E_s and A enables the rate coefficients at any temperature to be calculated from equation (5). These are also useful parameters for describing the effect of slag composition on sulphur transfer.

The parameter E_s is used to describe the rate of silicon transfer from slag to metal in those experiments (slags 8, 9, 14, and 16) in which the transfer was well defined, and these values are summarized in Table III. In the case of silicon transfer to the metal, the rate of uptake was initially constant and the rate coefficient k was calculated from this initial slope. No useful estimate of the silica activity can be made for the relatively complex slags and therefore 'A' values are not quoted for silicon transfer.

Effect of slag composition on sulphur transfer

Comparison of slags 1 and 2 containing similar alumina and silica contents allow the relative effects of lime and magnesia in aluminous slags to be assessed:

Slag	CaO	MgO	Al_2O_3	SiO_2	k_M	E_s
1	62	0	30	8	0·056	89
2	31	31	29·5	8·5	0·021	89

The transfer coefficient k_M, quoted for a temperature typical of blast-furnace conditions of 1480°C, indicates that CaO is preferable to MgO on a molar basis if a high rate of desulphurization is required, and the identical activation energy indicates that the superiority of CaO will be maintained at all temperatures.

The relative effects of lime and magnesia in siliceous slags can be assessed by comparison of slags 8 and 9:

Slag	CaO	MgO	Al_2O_3	SiO_2	k_M	E_s
8	28	27	6	39	0·0082	41
9	43·5	9·5	6	41	0·0087	32

Here the superiority of CaO over MgO is hardly significant in the rate coefficient, but could account for the objection to MgO expressed by some blast-furnace operators, and the activation energies are indistinguishable, to within the limits of experimental error.

TABLE III Parameters for silicon transfer from slag to metal

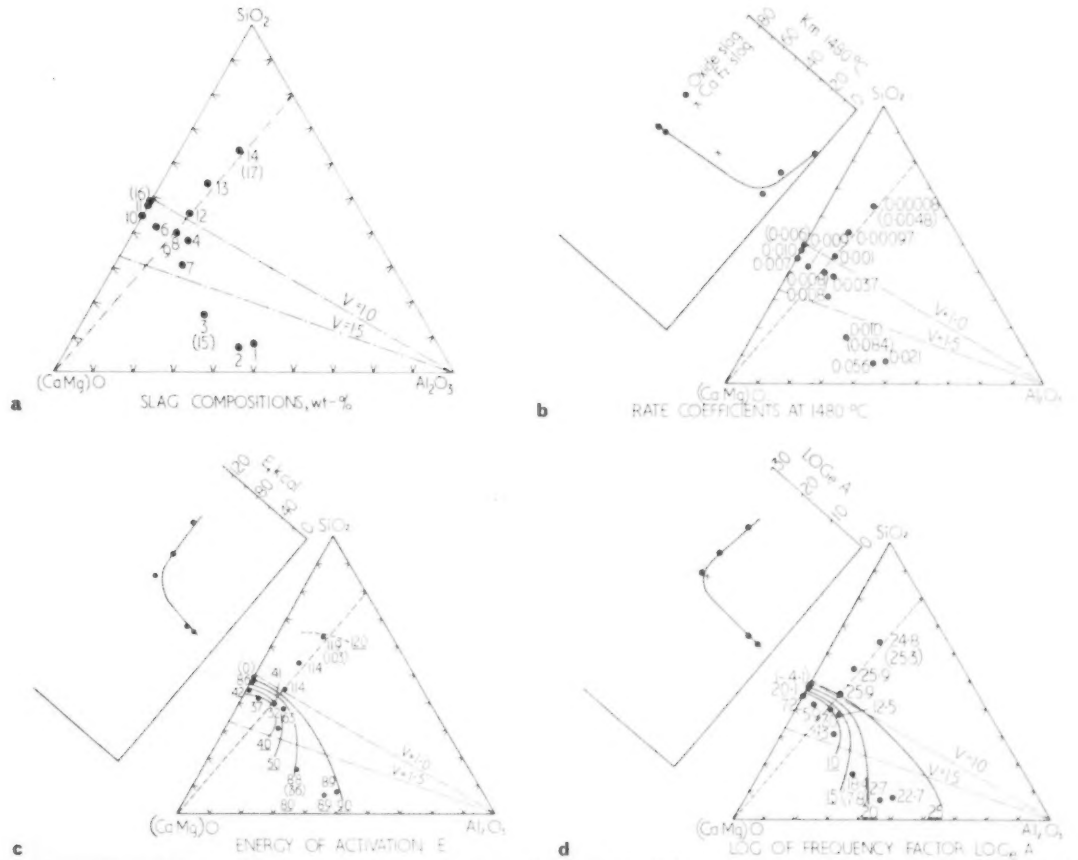
Slag no.	Temperature, °C	Rate	E_{Si} (kcal, g mol^{-1})
8	1440	0·0015	47
	1510	0·00187	
	1570	0·0032	
9	1400	0·00112	
	1500	0·00235	36
	1560	0·0036	
14	1440	0·000105	
	1500	0·00037	124
	1560	0·0013	
16	1485	0·0019	
CaF_2	1510	0·00235	34
	1565	0·0033	

The changes in sulphur transfer caused by replacement of lime by magnesia are negligible compared with those brought about by variations in the ratio of silica to alumina (compare slags 1, 2, and 3, with 4, 9, and 11) or of silica to lime (slags 9 and 12–14). These effects in the quaternary CaO–MgO–Al_2O_3–SiO_2 system can therefore conveniently be summarized by regarding CaO and MgO as equivalent, and considering the oxide slags as belonging to the pseudo-ternary (Ca–Mg)O–Al_2O_3—SiO_2 system. Plots of the rate coefficient k_M at 1480°C, the activation energy E_s and the 'frequency factor' A in this pseudo-ternary are given in Fig.5 on a weight percentage basis for later ease of application to commercial practice, and these plots show smooth variations with composition. The detailed discussion of Fig.5 is postponed until later, but some general comment may usefully be made. The overall effect of slag composition is that the addition of silica or alumina to a basic slag, i.e. as the composition moves out radially from the (Ca, Mg)O corner, produces a decrease in the rate of desulphurization. This is accompanied by an increase in the activation energy and hence in the rate of increase of sulphur transfer with increasing temperature. Too few slags have been investigated to allow much reliance to be placed on contour lines in Fig.5, but as most data exist along the line joining the (Ca, Mg)O corner and the 20%Al_2O_3, 80%SiO_2 composition, ternary sections along this line have been included to emphasize the abrupt effect of composition between 45 and 50%SiO_2.

The pseudo-ternary plots of Fig.5 may be further reduced to a pseudo-binary system by use of an acidity function derived by Negresco.[16] This was shown to correlate successfully, equilibrium data for the sulphur distribution between slag and metal for which the relative contributions of the four oxides CaO, MgO, Al_2O_3, and SiO_2 were found to be 1, $\frac{3}{4}$, 0, and −1; the data are then a function of acidity expressed by a silica fraction

$$N'_{SiO_2} = \frac{SiO_2}{CaO + \frac{3}{4}MgO + SiO_2}$$

Using this function as a composition parameter, the data for k_M, E_s, and A from the present investigation are given in Fig.6. The experimental points for the siliceous slags lie on one arm of the plot at the right of the diagram, and the aluminous slags are on a second branch on the left-hand side. The apparent success of



a compositions of slags used
b rate coefficients at 1480°C for transfer from metal to slag k_M (mg cm^{-2} min^{-1})
c experimental activation energies *E* (kcal/g mol)
d frequency factors *A* (g cm^{-2} min^{-1})

Unbracketed numerals are results for pure oxide slags. Bracketed numerals are slags of compositions indicated + 4·5 wt-% CaF_2

5 *Variation of sulphur transfer parameters with slag compositions given in percentage by weight*

this silica fraction in correlating rate data may be fortuitous and more slag compositions need to be investigated before the value of this function can be assessed.

The effect of calcium fluoride additions to oxide slags is shown in Table IV.

In all cases the addition of fluoride substantially increases the rate of sulphur transfer at 1480°C to an extent which cannot be explained on the basis of calcium fluoride being regarded as a basic addition equivalent to lime on a molar basis. The activation energy is also significantly lowered and the zero activation energy indicating a temperature-independent sulphur transfer coefficient for slag 16 is most surprising. These results conclusively show that the role of calcium fluoride is not simply to aid the solution of lime or to increase the basicity of slags, as has frequently been proposed, but rather that fluoride additions produce a direct increase in the rate of sulphur transfer.

Rate limiting process in sulphur transfer

The transfer of sulphur from metal to slag results in a build-up of negative charge in the slag and to restore electrical neutrality this must be balanced by the simultaneous transfer of some anion from slag to metal or of a cation to the slag from the metal, giving overall reactions such as:

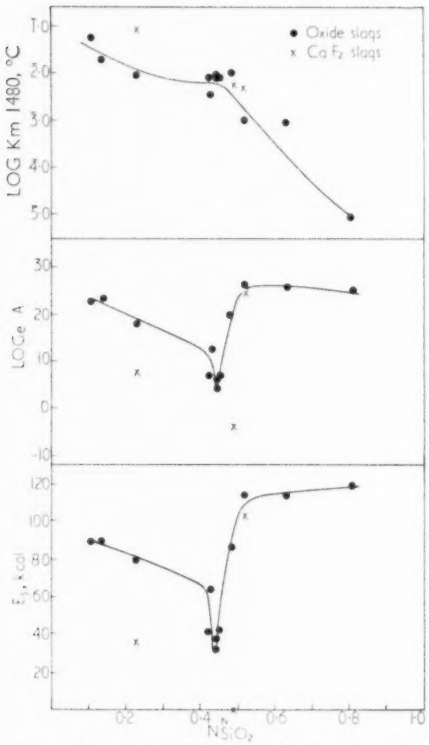
$$[S]+[Fe]=(S^{2-})+(Fe^{2+})$$
$$[S]+(O^{2-})=(S^{2-})+[O]$$

Thus the transfer of sulphur alone cannot be considered, and the behaviour of the accompanying elements must also be studied. The whole transfer process will involve three steps:

(i) diffusion of reactants, e.g. [S], [Fe], (O^{2-}) to the interface
(ii) reaction at the interface
(iii) diffusion of products, e.g. (S^{2-}), (Fe^{2+}), [O] from the interface.

If one of these steps is significantly slower than the other two, then the rate of this step will control the rate of the whole process and the identity of this step would be of considerable value in understanding the factors governing the sulphur transfer rate.

The experiments show that transfer of sulphur depends on slag composition, hence diffusion through the liquid metal cannot be rate limiting, and either diffusion in the slag or the rate of chemical reaction at the interface is the limiting step in the process. These two alternatives will now be considered.



a Rate coefficients at 1480°C for transfer from metal to slag k_M
b experimental activation energies E
c frequency factors A

6 *Variation of sulphur transfer parameters with slag composition expressed in terms of the Negresco silica fraction*

$$N_{SiO_2} = \frac{SiO_2}{CaO + \frac{2}{3}MgO + SiO_2}$$

Diffusion control

If sulphur transfer is diffusion controlled, the activation energies for diffusion and transfer should be identical, and it is therefore of interest to compare the activation energies for diffusion of sulphur,[17] oxygen,[18] and silicon[19] with those for sulphur transfer interpolated from Fig.5*c*. The data are given in Table V in which the activation energy for sulphur diffusion has been calculated from data given by Saïto *et al.*[17] and the limits of error on all figures are estimates by the present authors.

In all comparisons in Table V the activation energy for sulphur transfer lies within the wide probable errors for diffusion, but the diffusion values are so indefinite that the apparent agreement in Table V cannot be regarded as conclusive evidence for the diffusion control of sulphur transfer.

In addition to comparing activation energies, it would also be instructive to compare the rate of sulphur flow calculated by assuming a diffusion control mechanism, with that obtained by experiment. Thus, if sulphur diffusion is rate controlling, the flow of sulphur (J_S) away from the interface into the slag is given by Fick's first law:

$$J_S = D_S \frac{(S_i - S_B)}{X} \text{ g min}^{-1}$$

where D_S is the diffusion coefficient of sulphur in slag;[17] S_i and S_B are the sulphur contents in the slag at the interface and in the bulk, respectively; x is the thickness of the stagnant slag boundary layer. Initially S_B is zero, and if S_i is assumed to be in equilibrium with the metal then it may be replaced by $[\%S]\ L_S$, where L_S is the slag/metal sulphur distribution ratio. The above equation can therefore be rewritten:

$$J_S = D_S/x\ [\%S]\ L_S \text{ g min}^{-1}$$

This flow should be equal to the flow of sulphur across the interface from the present experiments, i.e.

$$J_S = k_M\ [\%S] \text{ g min}^{-1}$$

The equivalence between these latter two equations cannot be checked as the thickness of the boundary layer x is unknown, but if the equality is assumed for a 50%CaO, 40%SiO_2, 10%Al_2O_3 slag at 1440°C for which L_S is taken as equal to 100, a value of 0·03 cm is obtained for the slag boundary layer thickness, which is of the same order as that quoted by Darken.[20] This slag boundary layer thickness seems entirely reasonable and although this does not constitute proof of diffusion control, it indicates again that diffusion control could account for the observed results.

Chemical control

No activation energies for the reactions occurring at the interface are known, so no comparisons with the observed values can be made and the only method of attack is to set up a model of the reaction which is in accord with the experimental facts.

The most significant experimental fact is the equality for oxide slags of the activation energies for sulphur transfer to those for silicon transfer (Table VI), in those cases where the silicon transfer to the metal was sufficiently large for an activation energy to be calculated. (This equality was not found for the fluoride bearing slag no.16.)

The equality of the activation energies for oxide slags indicates that either: (*a*) the rate of sulphur transfer is governed by that of silicon (or vice versa) or (*b*) both transfers are controlled by a common factor. A possible explanation of the difficulty of sulphur transfer to these essentially acid slags, i.e. slags having few free O^{2-} ions, lies in the difficulty of replacing an oxygen ion of diameter 2·80 Å in the tetrahedral coordination shell of a silicon ion by the 31% larger sulphur ion (diameter 3·68 Å). This transfer would be

TABLE IV Effect of a 4·5 wt-% addition of calcium fluoride to oxide slags

Fluoride slag	Composition, mol % CaO	MgO	Al_2O_3	SiO_2	*k_M, g cm^{-2} min^{-1} Oxide	+CaF_2	E_a, kcal g mol^{-1} Oxide	+CaF_2	log$_e$A Oxide	+CaF_2
15	49	14	19	17	0·010	0·084	80	36	18·4	7·8
16	42	10	0	48	0·003†	0·006	90†	0	21†	−4·1
17	37	9·5	6	47·5	0·001	0·0048	114	103	25·9	25·3

* k_M at 1480°C
† Values interpolated from Fig.6

TABLE V Comparison of the activation energies for metal/slag transfer and for self-diffusion

Slag, wt-% CaO	SiO_2	Al_2O_3	Transfer energy, kcal	Diffusion isotope	Energy, kcal	Ref.
50	40	10	35±5	S35°	59±30	17
40	40	20	90±5	O18°	95±20	18
40	40	20	90±5	Si31°	80±20	19

TABLE VI Comparison of the transfer parameters for sulphur and silicon

Slag no.	Composition, mol % CaO	MgO	Al_2O_3	SiO_2	E_s	E_{si}
8	28	27	6	39	41	47
9	43·5	9·5	6	41	32	36
14	15	3	10	72	119	124
16 CaF_2	42	10	...	48	0	34

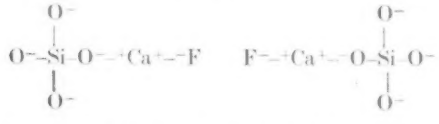
facilitated by silicon transfer from silicate anions to the metal which will inevitably leave free oxygen ions having a transient existence at the interface; these free oxygen ions could then exchange with sulphur in the metal. This transfer leaves the slag negatively charged and requires the simultaneous reduction of oxygen by carbon to keep the slag electrically neutral. The overall process may be represented by:

$$(SiO_4^{4-})+2\,[C]+2\,[S]=[Si]+2CO\uparrow+2(S^{2-})$$

Of the processes involved in this model it seems likely that the breaking of the four Si–O bonds each of 104 kcal g mol^{-1} energy,[21] i.e. to lift the silicon out of the 'potential well' due to its coordinating oxygen ions, would be a difficult process and could easily account for the observed activation energies. The sudden fall in the activation energy with decreasing acidity at about 47 wt-%SiO_2 would then reflect the influence of the increasing concentration of cations which is also responsible for the sudden decrease in the chemical activity of silica at about this composition.

This model accounts for the observed agreement between the activation energies for silicon and sulphur transfer in acid slags, but in basic slags the activation energy for silicon should exceed that for sulphur transfer due to the higher activity of free O^{2-} ions; no data are available to verify this.

If now the fluoride bearing slags are considered the lowered activation energies for sulphur transfer due to the fluoride additions (Table IV) indicates that the transfer process is energetically easier. Using the model of fluoride in silicate slags due to Baak[22] schematically:



it is apparent that exchange of sulphur with oxygen is unnecessary as direct replacement of fluorine by sulphur is possible. Owing to the low concentration of fluorine in the slags, the probability of this process occurring would be low, in accordance with the low observed values of A (Table II). However, the transfer of silicon to the metal will still require a considerable activation energy associated with the breaking of silicon–oxygen bonds which would exceed that for sulphur transfer by the mechanism above, as observed with slag 16, Table VI.

Although these arguments for chemical control are only qualitative, the model proposed satisfactorily fits the present observations and can also be used to provide an explanation of the dependence of sulphur transfer on silicon content observed by many workers.[4, 9–11] However, similar arguments can also be applied to the process of diffusion, if this is considered to be a bond breaking process, i.e. if diffusion in ionic melts is regarded as a chemical rather than a physical process, and it is impossible to decide from the present experiments whether the sulphur transfer process is controlled by diffusion in the slag of reactants or of products of the transfer process, or controlled by the mechanism of the transfer process at the interface.

Explanation of the variation of E and A with slag composition

Using the model discussed above of sulphur transfer involving bond breaking, the experimental activation energy, E_s, may be regarded as an indication of the strength of the bonds which must be broken in the transfer process. The highly siliceous slags have a large activation energy, e.g. 119 kcal at 72 mol%SiO_2 and 114 kcal at 57 mol%SiO_2 which suggests that oxygen ions are stably bonded in the anionic silicate complexes. As the lime (and magnesia) content is increased a sudden fall in E_s occurs when about 55% base has been added (*see* ternary section in Fig.5*c* or the right hand branch of Fig.6) indicating a weakening and breakdown of the slag structure, in agreement with the structural change at the composition inferred by Bockris *et al.*[23, 24] from viscosity measurements. A similar pattern is found when lime is added to the highly aluminous slags but the data are too limited to do more than note that more base is required to breakdown the aluminous lattice than for the siliceous slags.

The frequency factor A, also decreases in the same way with increasing basicity as does E_s, and this may be interpreted in terms of the proportion of successful jumps made by a sulphur atom. But according to the proposed model this will largely depend on the transfer of silicon which will be related to the activity of silica in the slag.

Application to iron and steelmaking processes

The results of the present investigation are strictly applicable only to the transfer of sulphur from pure iron saturated with carbon to simple 'iron oxide free' slags, and cannot be applied directly to more complex commercial processes, as the simultaneous transfer of other elements with sulphur[14] and the presence of other elements in the iron[4, 9–11] are known to affect the transfer rate.

In the crucible of a blast-furnace the highly reducing conditions result in slags of low iron oxide content approximating to compositions covered by the present investigation. The metal is, however, highly alloyed with manganese, silicon, and phosphorus, and although these may be expected to affect the actual rates of transfer, the rates will probably vary with slag composition in a similar pattern to that found with pure iron–carbon melts. If this assumption is valid the influence of slag composition on sulphur transfer in the blast-furnace can be obtained from Fig.5*b* in which the field of blast-furnace slags lies between the

lines of basicity ratio* 1·0 and 1·5 and with alumina contents up to 30 wt-%. This indicates that the highest rates of desulphurization are to be expected with basic slags (high V ratio) containing the minimum possible alumina, while much lower rates should be obtained with acid slags of high alumina content which would therefore be less likely to reach equilibrium with the metal.

The detailed extrapolation from the present studies to steelmaking conditions is impossible, but it is of interest that the addition of calcium fluoride to oxide slags, in all cases substantially increases the rate of sulphur transfer beyond any possible effect of calcium fluoride on the basicity of the slag, as noted earlier. This therefore resolves the controversy which has existed for many years as to whether fluoride additions have any direct value in promoting transfer of sulphur to the slag.

It is of interest that the highly aluminous slags (nos.1–3) have high transfer coefficients, showing that the Perrin desulphurizing process utilizing this type of slag is successful owing not only to the thorough mixing used in the process, but also to the inherently high desulphurizing rates of these slags.

CONCLUSIONS

1. The initial transfer of sulphur from metal to slag obeys a first order reaction equation of the form

$$d[S]/dt = k_M[S]$$

2. The rate coefficient k_M is generally increased by:

(i) increasing the temperature
(ii) increasing the slag basicity
(iii) adding calcium fluoride to the slag.

3. In the normal range of blast-furnace slags, the maximum rate coefficient occurs with alumina-free slags of high basicity.

4. The transfer process is thermally activated, and the effect of temperature on the rate coefficient for any slag obeys an Arrhenius equation:

$$k_M = A \exp(-E/RT)$$

where the activation energy E_s, varies between 0 and 120 kcal g mol^{-1}, depending on the slag composition.

5. The transfer of sulphur to pure oxide slags is accompanied by the transfer of silicon to the metal with the same activation energy. This indicates that both sulphur and silicon transfer are limited by the same factor, which is probably the difficulty of removing a silicon atom from its coordination shell of oxygen atoms.

6. With fluoride-bearing slags the activation energy for silicon transfer exceeds that for sulphur, suggesting different mechanisms for the two processes; possibly the removal of silicon from its oxygen environment and the direct exchange of fluorine and sulphur ions respectively.

ACKNOWLEDGMENTS

One of us (K.A.S.) acknowledges the financial support of the Andrew Carnegie Research Fund Committee of The Iron and Steel Institute. We both wish to thank Professor A. G. Quarrell for his encouragement and for the provision of laboratory facilities, and also our colleagues for many discussions, particularly Dr W. R. Maddocks of Sheffield University and Dr J. B. Henderson of the Carnegie Institute of Technology, Pittsburgh.

* Basicity ratio taken as $V = \dfrac{\text{wt-\%}(CaO + MgO)}{\text{wt-\%}\ SiO_2}$

APPENDIX I

Preparation of (Fe + FeS + FeS^{35}) from aqueous $Na_2S^{35}O_4$ solution

The active isotope was obtained as an aqueous solution of $Na_2S^{35}O_4$ from the Radio Chemical Centre, Amersham. The quoted radiochemical purity in this form is >99%, and is to be preferred to FeS^{35} or S^{35} which are available but of unknown radio chemical purity, as contamination by other radioactive isotopes is undesirable in counting experiments.

In the conversion of active sulphate into FeS^{35}, about 4 g anhydrous Na_2SO_4 was spread evenly in a rectangular boat machined from armco iron, to 10 cm × 1·3 cm × 1·7 cm, external and 6 cm × 1 cm × 0·5 cm internal dimensions. The aqueous solution of $Na_2S^{35}O_4$ (2 mc/0·5 ml) was then carefully pipetted on to the carrier sulphate, and the crucible was charged into a silica working tube of a Nichrome-wire wound furnace. The ends of the working tube were fitted with rubber bungs and water-cooled. Hydrogen was then passed through the tube and after about ¾ h the furnace was switched on and the temperature raised to 1000°C over a period of about 2½ h; this temperature was maintained for 15–20 min and the furnace was then switched off. The effluent gas was passed through an acid solution of lead acetate to collect the small amount of sulphurous gases carried over. As a further precaution, all operations were carried out in a fume cupboard.

After cooling, the crucible was transferred to a flask containing an ammoniacal solution of ferrous sulphate. Ion exchange occurred and a precipitate of ferrous sulphide was obtained. The precipitate was allowed to stand for several days and then filtered on a Bruckner filter. The mixture of oxides and hydroxides of iron and ferrous sulphide, and filter paper was charged into a graphite crucible in a vertical tube furnace, and after drying for 3–4 h at 300–400°C, 200 g of carbon-saturated iron was added and the furnace temperature was raised to 1400°C. All gases coming from the furnace were passed through solutions of potassium chromate and then lead acetate to remove traces of sulphur compounds, before escaping to the atmosphere.

The liquid iron containing active sulphur was then withdrawn by suction into a silica tube, providing convenient rods for additions to the transfer experiments. All operations were carried out with scrupulous care to avoid any spread of radioactivity.

REFERENCES

1. L. C. Chang and K. M. Goldman: *Trans. AIME*, 1948, **176,** 309–329.
2. G. Derge *et al.*: *ibid.*, 1950, **188,** 1111–1119.
3. T. Rosenquist: *ibid.*, (discussion), 1336–1338.
4. O. V. Travin and L. A. Schvartsmann: *Zhur. Fiz. Khim.*, 1955, **29**(ii), 2031.
5. T. Saîto and Y. Kawai: *Sci. Rep. RITU*, 1955A, **7,** 402.
6. N. J. Grant *et al.*: *Trans. AIME*, 1951, **191,** 666.
7. G. Hatch and J. Chipman: *ibid.*, 1949, **185,** 274–284.
8. C. E. A. Shanahan: *JISI*, 1955, **180,** (2), 140–144.
9. N. J. Grant *et al.*: *Trans. AIME*, 1951, **191,** 672.
10. K. M. Goldman *et al.*: *ibid.*, 1954, **200,** 534–540.
11. Y. Kawai: *Sci. Rep. RITU*, 1956A, **8,** 352.
12. P. T. Carter: *Iron Steel*, 1953, **26,** 297–302.
13. W. Oelsen and H. Maetz: *Arch. Eisenhüt.*, 1943, **16,** 283–298.
14. S. Ramachandran *et al.*: *AIME Elec. Furn. Steel Conf. Proc.*, 1955, **14,** 338.
15. K. Balajiva *et al.*: *JISI*, 1946, **153,** 115–150.
16. T. T. Negresco: *Rev. de Met. Acad. Rep. Pop. Roumaine*, 1957, **2,** 5–50.

17. T. Saîto and Y. Kawai: *Sci. Rep. RITU*, 1953A, **5**, 460.
18. T. B. King and P. J. Koros: 'Kinetics of high temperature processes', 80–85; 1959, London, Chapman and Hall.
19. H. Towers and J. Chipman: *Trans. AIME*, 1955, **203**, 769.
20. L. S. Darken: 'The physical chemistry of steelmaking', 106; 1958, London, Chapman and Hall.
21. T. L. Cottrell: 'The strengths of chemical bonds'; 1954, London, Butterworth's Scientific Publications.
22. T. Baak: 'The physical chemistry of steelmaking'; 1958, London, Chapman and Hall.
23. J. O'M. Bockris *et al.*: *Trans. Farad. Soc.*, 1955, **51**, (2), 1734–1748.
24. J. O'M. Bockris and D. C. Lowe: *Proc. Roy. Soc. A*, 1954, **226**, 423–435.

Liquidus and solidus relations in iron-rich iron–carbon alloys

R. A. Buckley and W. Hume-Rothery

SYNOPSIS

The equilibrium diagram of iron-rich iron–carbon alloys has been determined by a combination of the methods of thermal analysis and microscopical examination of quenched specimens. The results are in good agreement with the curves given in other recent work, and confirm that Hansen was correct in rejecting experimental points which made the equilibrium diagram appear to be so uncertain. 1889

INTRODUCTION

The previous work on the iron–carbon equilibrium diagram has been summarized concisely by Hansen.[1] For the liquidus curve, the results of different investigators, differed considerably, while for the γ-solidus curve the variation was even greater. Hansen preferred the work of Adcock[2] for alloys of up to 5 at-% carbon, and of Ruer and Goerens[3] for alloys from 5% to 17% carbon as representing the most reliable course of the phase boundaries. Very little accurate work has been done on the δ solidus and γ solidus, there being no results of any significance on the γ solidus between 5% and 9% carbon.

On Adcock's diagram the liquidus and solidus fall steeply from the freezing point of pure iron (1533°C) to a peritectic horizontal at 1493°C where the following reaction takes place:

$$\delta\ (0{\cdot}46\%\text{C}) + \text{liquid}\ (2{\cdot}33\%\text{C}) \rightarrow \gamma\ (0{\cdot}74\%\text{C})$$

The γ liquidus and solidus then fall less steeply until the eutectic temperature is reached. At 1153°C the liquid freezes as a eutectic mixture of γ-phase+pure carbon. The eutectic point is taken as 17·1% carbon from the work of Ruer and Goerens, and the limit of γ solid solubility as 8·79% carbon. The latter figure was obtained by an extrapolation of Adcock's results to the eutectic horizontal.

From an assessment of some thermodynamical data, Darken and Gurry[4] have put the peritectic temperature at 1499°C. This value has been quoted in some recent publications. This temperature refers to a freezing point for pure iron of 1539°C which also exceeds Adcock's value by 6°C. Both of these figures refer to the 1927 international scale of temperature on which the fixed points are nickel=1455°C and palladium=1554°C; these points are 2° higher than on the 1948 temperature scale. In previous work at Oxford[5–7] the freezing point of BISRA 'H' iron has been consistently measured at 1533°C but as there is usually a difference of 1–2°C between the value given by the cooling curve and that given by the heating curve, this temperature is probably 1–2°C too low. A value of 1535°C is in agreement with the work of Boulanger[8] who has re-determined the transition points in pure iron and obtained 1536°C for the freezing point.

A series of alloys has been prepared with carbon contents of up to 20 at-% and the temperatures of the liquidus, solidus, and delta-gamma phase boundaries have been determined. This work is the first stage of the project for the determination of the ternary diagrams of the form iron–carbon–M, where M is another metal.

EXPERIMENTAL

Alloys have been made up using BISRA 'H' iron of 99·95% purity (<0·005% carbon by weight) and spectroscopically pure graphite. Also, some of the lower percentage carbon alloys were prepared using a master alloy containing 6·25 at-% carbon supplied by BISRA. This alloy was of similar purity to the 'H' iron.

Ingots of about 40 g each were melted in vacuum ($<10^{-4}$ cm) in either pure alumina or pure thoria crucibles. All alloys containing more than 4 at-% carbon were melted in thoria crucibles because they became contaminated with aluminium if alumina were used. Below 4% carbon the reduction of alumina was negligible, i.e. <0·01%Al in the ingot. Several alloys in this range were melted in thoria, but there was no difference in the results from those melted in alumina.

Manuscript received 9 September 1960 (BISRA ref. MG/A/84/60).

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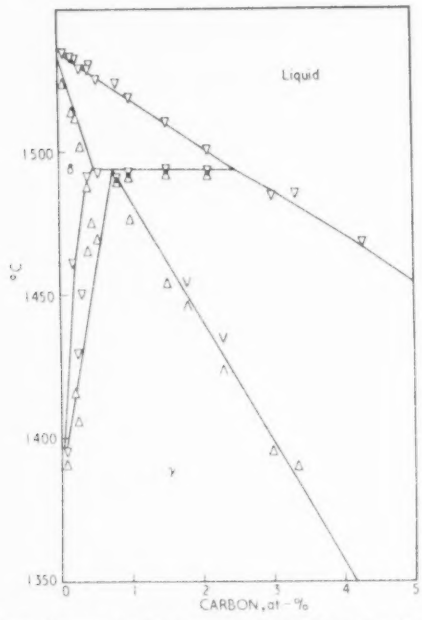
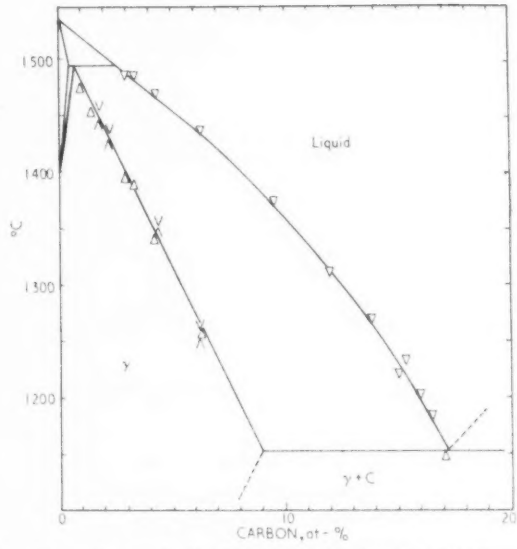


1 *Phase diagram for* Fe–C *above 1350 C: from 0 to 5%C*



2 *Phase diagram for* Fe–C *above 1100 C: from 0 to 20%C*

The pure alumina and pure thoria crucibles were supplied by Morgan Refractories Limited.

The thermal analysis furnace and the procedure for obtaining cooling and heating curves have been described previously by Hellawell and Hume-Rothery. The method employed for this investigation was the same. All temperatures recorded were measured using Pt/Pt+13%Rh thermocouples which were calibrated frequently against the freezing point of pure nickel, 1453°C. Pure alumina and thoria coated alumina thermocouple sheaths were used. All the ingots were examined microscopically after thermal analysis to ensure that they were homogeneous in composition. The chemical analyses were carried out by Messrs Johnson, Matthey and Co. Ltd. A number of samples were taken from each cooling curve ingot to ensure that the chemical analysis was representative of the whole ingot. The figures given for the analyses are the mean of up to six determinations per ingot.

The liquidus arrests on the cooling curves were accompanied by less than 1°C of supercooling; for the alloys of high carbon content no supercooling whatsoever occurred. The accuracy of the liquidus arrests should be of the same order as that of Hellawell and Hume-Rothery, i.e. ±1–2°C. At very high concentrations of carbon some segregation was observed in the ingots, and in certain cases parts of the ingot had to be dissolved away, before chemical analysis, to remove pieces of the thoria crucible which adhered to the surface. Any errors are likely to be due to a non-representative chemical analysis rather than to errors in temperature measurement.

The arrest corresponding to the peritectic horizontal was generally accompanied by about 1°C of supercooling but was reproducible to ±2°C in all the alloys. The heating curve arrests were about 1°C higher than the cooling curve arrests.

The δ solidus falls very steeply so that any segregation in the ingot makes the heating curves unreliable. Alloys were annealed for at least 2 h in the δ-phase region below the solidus in order to minimize this effect. The arrests for the δ solidus should be accurate to ±2°C.

The freezing range in the γ+liquid region is very wide so that all arrests corresponding to the γ solidus were very weak and consequently could not be measured with as great an accuracy as the other arrests. The accuracy will not be better than ±5°C in this region.

To verify the thermal analysis results some alloys were annealed at a temperature near to the γ solidus, quenched to room temperature, sectioned, and examined microscopically for traces of quenched liquid. The difficulty with this type of work, using iron–carbon alloys, is that quenched specimens usually have a coarse martensitic structure which makes the detection of the first sign of quenched liquid very hazardous. Errors due to temperature lag between the thermocouple and specimen have been discussed previously.[6] A pressure of about 5 cm of hydrogen in the annealing furnace ensured that the temperature of the specimen could be measured to within 2°C.

RESULTS

The temperatures of the thermal arrests are listed in Table I. Cooling curve arrests are shown with the apex of the triangle pointing downwards and heating curve arrests with the apex uppermost (Figs.1 and 2). The temperature brackets from the anneal and quench experiments are indicated by open triangles on the diagram thus ▽△.

The δ liquidus and solidus fall steeply from the freezing point of pure iron to the temperature of the peritectic transformation (1494°C) where the following reaction takes place

$$\delta\ (0{\cdot}5\%C) + \text{liquid}\ (2{\cdot}47\%C) \rightarrow \gamma\ (0{\cdot}75\%C)$$

At compositions greater than 2·47% carbon the γ phase solidifies directly from the melt along a liquidus

TABLE I Thermal arrests for Fe–C alloys

Alloy no.	Synthetic, at-%	Analysed, at-%	Type	Temp., °C
1	3·6	3·35	L	1483·4
			S	1391·7
2	1·0		L	1517·6
			S	1477·9
			P_e	1490·8
			P_H	1492·4
3	0·4	0·46	L	1529·0
			γ/δ_H	1476·5
4	2·0	2·11	L	1498·7
			P_e	1491·3
			P_H	1492·7
5	0·7	0·82	L	1522·6
			P_e	1489·3
			P_H	1490·6
6	6·25	6·3	L	1433·4
			S	1260·4
7	1·5	1·52	L	1508·3
			S	1455·5
			P_e	1492·0
			P_H	1493·3
8	0·6	0·55	L	1523·9
			P_e	1490·8
			δ/γ_H	1480·4
10	4·42	4·27	L	1465·6
			S	1343·6
13	0·2	0·19	L	1531·7
			S	1515·5
			δ/γ_H	1416·8
			γ/δ_e	1459·5
14	0·5		L	1527·7
			δ/γ_H	1466·5
			P_e	1489·9
			P_H	1490·0
19	0·3		L	1528·0
			S	1503·0
			δ/γ_e	1448·5
21	3·0		L	1482·5
			S	1397·0
29	10·0	9·5	L	1370·5
29	0·25	0·24	L	1530·9
			S	1513·7
			δ/γ_e	1427·8
			δ/γ_H	1407·2
31	0·1	0·065	L	1532·9
			S	1530·6
			δ/γ_e	1393·0
			γ/δ_H	1392·0
34	15·0	15·3	L	1229·9
35	12·0		L	1308·5
37	14·0	13·8	L	1265·7
38	17·1		Eg	1152·0
40	15·5	15·0	L	1218·7
41	16·5		L	1181·8
42	16·0		L	1199·5

L Liquidus point from cooling curve
S Solidus point from heating curve
δ/γ_H $\gamma\rightarrow\delta$ transition from heating curve
δ/γ_e $\delta\rightarrow\gamma$ transition from cooling curve
P_H Peritectic transformation from heating curve
P_e Peritectic transformation from cooling curve
Eg γ+graphite eutectic from heating curve

line which is almost the direct continuation of the δ liquidus above the peritectic temperature.

The γ solidus falls steeply from the peritectic, following a straight line to the γ+graphite eutectic at a temperature of 1153 C. The latter temperature is generally accepted as fixed and, as most of the published work is in agreement on this fact, this region of the diagram has not been investigated very closely. The limit of solid solubility of the γ phase is 8·98% carbon.

The $\gamma/\gamma+\delta$ and $\delta/\delta+\gamma$ phase boundaries are somewhat uncertain owing to the large hysteresis error associated with this solid state transformation, but the results indicate that the $\delta/\gamma+\delta$ boundary is slightly convex and the $\delta+\gamma/\gamma$ boundary is straight.

The δ liquidus, when extrapolated back to zero percent carbon gives a value of 1535 C for the freezing point of pure iron. No actual measurements were taken above 1533 C which is the freezing point of 'H' iron. This would indicate that either the liquidus at very low carbon content is flattened or, more likely, that carbon removes the last traces of oxygen from the iron which might otherwise be contaminated with small quantities of oxygen from the crucible or the atmosphere. A similar state of affairs is evident in the iron–aluminium system at low aluminium contents.[10]

The γ liquidus and solidus extrapolated back to zero percent carbon give the hypothetical freezing point of γ iron as 1528 C. This seems higher than that determined by Gibson and Hume-Rothery for other alloy systems (1514 C) and that of Hellawell and Hume-Rothery (1520 C) but is closer to the value suggested by Darken and Gurry from thermodynamic data (1532 C on the old scale).

At higher carbon contents the liquidus arrests were not so sharp as at the lower percentages, whilst trouble was experienced in the chemical analysis of ingots of composition near to the eutectic, due to segregation and undercooling. For this reason it was impossible to determine directly the exact composition of the eutectic by microscopical examination of the ingot. Also, eutectic arrests on the cooling curves showed considerable undercooling due to the presence of the metastable γ+carbide eutectic some 6 C below the stable γ+graphite eutectic.

For alloys containing up to 15·3 at-% carbon the greatest difference between the synthetic and analysed composition was 0·5 at-% (=0·12% carbon by weight) and in view of the difficulties of analysing the high-carbon alloys, it was considered justifiable to use the synthetic compositions of alloys 16·0 and 16·5, and the ingots of these were not analysed. A value of 17·3% carbon was obtained by extrapolation of the liquidus to cut the eutectic horizontal. This value is in good agreement with previous work.

The hyper-eutectic alloys have not been studied as they have been the subject of several recent investigations.[12]

CONCLUSION

The present work establishes the iron–carbon equilibrium diagram satisfactorily, and shows that Hansen was justified in rejecting the results of Unimo[11] for the liquidus and of Honda and Endo[9] for the γ solidus and in taking the highest values of Ruer and Goerens for the γ liquidus.

In a later paper it is hoped to examine the iron–carbon diagram from a thermodynamical viewpoint and to compare it with other iron alloy systems.

ACKNOWLEDGMENTS

The authors thank the USAF Air Research and Development Command for financial assistance towards the cost of this research. Thanks are also due to BISRA for the award of a research bursary to R.A.B., and for grants towards the cost of the work.

REFERENCES

1. M. Hansen: 'Constitution of binary alloys', 1958, McGraw-Hill.
2. F. Adcock: *JISI*, 1937, **135**, 281–292.
3. R. Ruer and F. Goerens: *Ferrum*, 1916, **14**, 161.
4. L. S. Darken and R. W. Gurry: 'Physical chemistry of metals', McGraw-Hill.

5. G. B. Harris and W. Hume-Rothery: *JISI*, 1953, **174**, 212–218.
6. A. Hellawell and W. Hume-Rothery: *Phil. Trans.*, 1957, **249**, 417–459.
7. W. S. Gibson and W. Hume-Rothery: *JISI*, 1958, **189**, 243–250.
8. C. Boulanger: *Compt. Rend.*, 1955, **241**, 1133–1135.
9. K. Honda and H. Endo: *Sc. Rep. Tôhoku Univ.*, 1927, **16**, 235.
10. J. R. Lee: *JISI*, 1960, **194**, 222–224.
11. S. Unimo: *Sc. Rep. Tôhoku Univ.*, 1935, **23**, 720–725.
12. E. T. Turkdogan and L. E. Leake: *JISI*, 1955, **179**, 39–43.

Estimation of hydrogen in pickled steel by vacuum extraction at 700°C

K. Sachs and M. Odgers

SYNOPSIS

A technique for ductility testing and hydrogen analysis of pickled specimens is described. The scatter of analysis results is high; although moisture adsorption at the surface contributes to the scatter, the main cause is variation in the response to pickling of similar specimens: the fluctuations are due to the samples and not the analysis; sulphide inclusions have an appreciable influence on hydrogen absorption in pickling. Gas evolution at temperatures higher and lower than 700 C is considered.

1866

INTRODUCTION

THE ANOMALOUS OCCLUSION of hydrogen in steel and the concomitant deterioration in properties are of scientific interest and of practical relevance in industry, and a substantial literature has accumulated. Much effort has been expended in the analysis of steels for hydrogen introduced in steelmaking and in welding; hydrogen embrittlement in pickling and electroplating has also received attention. It is surprising, therefore, that work on the amount of gas absorbed in pickling and electroplating has been very restricted.

An extensive survey of the literature revealed some isolated hydrogen determinations on pickled or electrocharged steels[1–4]; most systematic studies quoted analysis results which, while internally consistent, cannot be compared with those of other workers,[5,7–9] and only one of them[11] employed a really adequate method of analysis.[10]

The effect of pickling on the hydrogen absorption and ductility of various steels has been investigated at the GKN Group Research Laboratories. The present paper describes the methods employed and some experiments carried out in the course of developing the routine specimen preparation and analysis. The scatter of results is compared with figures taken from published papers and reasons for the fairly high random fluctuations in the gas analysis figures on pickled specimens are considered in detail.

PROBLEMS OF HYDROGEN ANALYSIS IN PICKLED SPECIMENS

In taking samples for gas analysis, special precautions must be observed to avoid loss of hydrogen. In steelmaking and weld samples hydrogen is lost mainly at high temperatures and rapid cooling is the essential requirement; some hydrogen may also be evolved at room temperature, however, and this tendency increases with the total hydrogen content. In pickling and electrolytic charging, substantial hydrogen contents can build up and it is essential that no time should be lost between charging and analysis. In view of the large fluctuations in hydrogen absorption between similar specimens subjected to similar pickling conditions, it seemed desirable to determine ductility and hydrogen content on the same specimens. In the present work, therefore, the pickled specimens were broken in a fairly rapid bend test and one half was used for analysis; in some cases the other half was kept in solid CO_2 for analysis at a later date, but mostly the remaining pieces were stored at room temperature. It was necessary to estimate how much hydrogen was likely to be lost during bend testing.

Evolution of hydrogen at room temperature may proceed more rapidly in a vacuum than in the atmosphere. For this reason it was essential to keep the analysis apparatus fully evacuated and ready to detect gas evolution as soon as the specimen was introduced. In practice the specimens entered the apparatus through a mercury column and were then taken into and removed from the furnace tube by a magnet; some air inevitably enters the mercury column together with the specimen; the gas introduced in this way was pumped off and checked for hydrogen before the analysis proper; the specimen was held magnetically below the surface of the mercury during this operation.

In vacuum annealing at temperatures of 600–700°C, reactions may occur between various elements in the steel, primarily carbon, and oxygen or moisture in the form of inclusions or adsorbed films. It is desirable,

Manuscript received 1 June 1960.
Dr Sachs is Head of the research metallurgy section, GKN Group Research Laboratory, Wolverhampton; Miss Odgers is in the same section.

TABLE I Evolution of hydrogen in a vacuum at room temperature

Sample no.	Steel	Method of charging with hydrogen	Time at room temperature	Gases at room temp. Total gas, ml/100 g	Hydrogen, ml/100 g	Gases at 700°C Total gas, ml/100 g	Hydrogen, ml/100 g	Other details
346 (a)	Mild steel	30-min pickle cold 50% HCl	¾ h	0·32	0·23	4·37	2·36	
346 (b)	Mild steel		35 min	nil	nil	3·14	1·53	Stored 24 h at −78°C
344 (a)	En 1a	30-min pickle cold 50% HCl	19 h	5·4	4·78	3·46	*	H not determined at 700°C because of leak in Pd tube
344 (b)	En 1a		7¼ h	5·12	4·39	6·28	2·32	Stored 48 h at −78°C
345 (a)	En 1a	30-min pickle cold 50% HCl	16 h	5·87	5·54	7·72	3·10	Material stretched to maximum load in tensile test
345 (b)	En 1a		5 h	4·17	3·56	6·78	1·89	Material stretched to max. load in tensile test; stored 4 days at −78°C
348 (a)	Silver steel	30-min pickle cold 50% HCl	63 h	1·85	1·21	2·04	0·74	Material heat-treated and cold-worked
348 (b)	Silver steel		17½ h	1·68	1·52	1·74	0·25	Material heat-treated and cold-worked; stored 70 h at −78°C
111	Cyanided	3-min pickle cold 50% HCl in contact with FeS	3 h	1·5	*	1·29	*	Sample analysed before provision of Pd tube

* Not established

therefore, that the sample should be perfectly clean on entering the apparatus, and samples taken in steel-making are often machined all over. This is impossible in the case of pickled specimens, because the surface layers of the steel are richest in hydrogen. Every care must be taken to remove all traces of acid from the specimen and to dry it thoroughly after washing.

VACUUM EXTRACTION APPARATUS

The apparatus employed, similar in principle to that developed by Newell,[12] consists primarily of a fused silica furnace with a nickel/chromium resistance winding and appropriate high-vacuum equipment; the specimens are introduced via a barometer tube. The furnace is evacuated by a mercury diffusion pump which sweeps any gases evolved by the specimen in the furnace into a combined Töpler pump and McLeod gauge; a palladium tube surmounts the gauge bulbs. A second mercury diffusion pump evacuates the system, backed by a rotary vacuum pump.

There is some variation in the zero reading of the pressure gauge because of tailing of mercury in the capillary tube connecting the calibrated bulbs. The maximum error in analysis from this cause did not exceed ±2½%, in investigations on pickled specimens where the lowest hydrogen contents of interest were of the order of 2·0 ml/100 g.

A slight 'blank' on the furnace when hot is corrected by plotting readings on the McLeod gauge scale against furnace time, the blank being about 2 mm/h on bulb 1. The blank on the other bulbs is not significant, only 2 mm on bulb 2 for the first two hours' furnace time and negligible thereafter. Analysis times varied from 1½ h to about 7½ h.

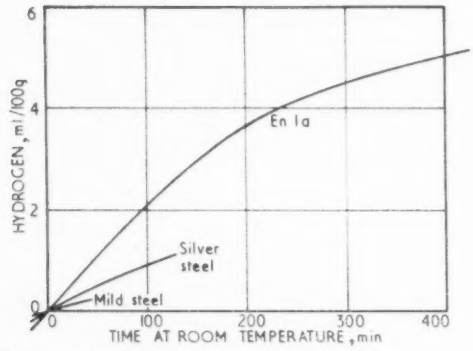
BEND TEST AND ANALYSIS

In the bulk of the work the specimens were charged by pickling in cold 50% HCl, using the time of immersion as the experimental variable. Each specimen was pickled in 50 cm³ of fresh solution, washed in running water under a tap, wiped with a cloth, and broken in the bend test.

The bend test was carried out on a Hounsfield tensometer, using a 3-point jig which bends the bar a maximum of 90°. A load-displacement graph was recorded during the test and the values at the point of fracture were obtained from the graph and tabulated as breaking load and breaking strain. For fairly brittle materials, like silver steel, the load readings were more sensitive to experimental variables than the strain; for ductile materials, like mild steel, the strain readings gave the better indication of embrittlement. The test has some disadvantages for ductile materials and for certain applications a 'repeated bend test' is preferred.[13]

One-half of the broken specimen was analysed immediately after the bend test. No attempt was made to machine away the material near the fracture, which may have lost some hydrogen during the bend test[14]; this possibility is briefly examined in a later section. The broken half selected for analysis was dried and degreased in acetone and ether, weighed, and inserted in the apparatus.

The time from the end of pickling to insertion in the analysis apparatus was 5–10 min. Some idea of the probable hydrogen loss in this short period can be obtained from a few experiments in which specimens were held in the vacuum extraction apparatus at room temperature to collect any hydrogen evolved; they were removed when two successive readings showed no increase in gas evolution. The results, presented in Table I, show that mild steel specimens lost very little hydrogen at room temperature, perhaps because they had been lightly cold worked[15,16]; a high-sulphur free-cutting steel evolved a considerable proportion of its hydrogen at room temperature, even with specimens cut from lengths of rod broken in a tensile test. Some hydrogen was extracted at room temperature from silver steel and from cyanided specimens. The actual rate of evolution is plotted in Fig.1 for representative specimens; the graphs are extrapolated backwards for 10 min and the estimated hydrogen losses are 0·27 ml/100 g for free-cutting steel En1a (4·7% of the hydrogen evolved at room temperature), 0·08 ml/100 g for silver steel, and 0·07 ml/100 g for mild steel. These figures are in rough agreement with estimates of losses before analysis from specimens cut from weld deposits.[17] It is evident that the amount lost in the first 5–10 min



1 *Hydrogen evolution* in vacuo *at room temperature*

outside the apparatus, i.e. at 1 atm and not in a vacuum, is not likely to be appreciable.

SCATTER OF ANALYSIS FIGURES

In view of the special features of the hydrogen analysis of pickled steel discussed above, some random scatter of analysis results and of true hydrogen contents was to be expected. As a check of the reliability of the analyses, the scatter is compared in Table II with that obtained by other workers in determinations of hydrogen contents derived from various sources: steelmaking, charging with hydrogen by melting under a hydrogen-rich atmosphere, by cathodic treatment, and by pickling. The mild steel specimens used in the present work came from two coils of wire, quite probably from the same heat or even ingot. The scatter is not, therefore, likely to be due mainly to steelmaking differences, but must have been introduced in pickling, washing, or drying.

Table II shows that in spite of the careful preparation of the specimens the random scatter of the 'steelmaking' samples was quite appreciable, due, no doubt, to variations in furnace conditions and sampling losses. When the melt was prepared under controlled conditions[18] the scatter was extremely low.

Specimens pickled for various times in 1 N and 10 N sulphuric acid[8] also showed appreciable scatter but values for similar pickling time are rather more reproducible than is suggested by the scatter quoted in Table II; however, the figures are based on gas evolution at 170 C and although check analyses established that the gases consisted largely of hydrogen and that less than 10% more gas was evolved in subsequent vacuum extraction at temperatures up to 800 C, some doubt must remain whether all the hydrogen absorbed was in fact included in the analysis. The analyses of electrocharged specimens[2,11] show considerably more fluctuation; in the experiments yielding the most erratic results, the analysis samples were machined from tensile specimens after electrocharging; considerable loss of hydrogen may occur in machining and elaborate precautions are sometimes taken to prevent this loss by cooling the work with liquid nitrogen during machining.[19] Extremely reproducible results were obtained on a small number of Armco iron and mild steel (SAE 1020) specimens pickled and prepared for analysis under unspecified conditions.[10]

The scatter of analysis results in the present work was extremely high. It is based on sufficient experiments to be fully representative of the fluctuations likely to arise in pickling and analysis. When the level of hydrogen in the steel is higher owing to prolonged pickling or a high sulphur content in the steel, the fluctuations are rather greater than the value of ±3·0 ml/100 g given in Table II but represent a much smaller proportion of the actual hydrogen content. This must be attributed to random variations in the response of similar specimens to identical pickling treatments; it is likely to be most pronounced at longer pickling times and higher hydrogen contents. However, the scatter could be attributed to variations in true hydrogen content only after an assessment of

TABLE III Loss of hydrogen in the bend test

Pickling time	Type of specimen	No. of samples	Hydrogen mean, ml/100 g	Other gases mean, ml/100 g
0	Broken	8	1·08	4·51
	Cut	5	0·97	3·48
30 min	Broken	42	3·17	3·59
	Cut	13	3·90	5·10

TABLE II Scatter of hydrogen analysis results

Source of hydrogen	Type of steel	Authors	No. of samples	Range of hydrogen contents, ml/100 g	Scatter*, $\pm 2\sigma$
Steelmaking	Basic electric 0·9%C, 1·7%Cr	Hobson and Rait[33]	217	3·1– 7·8	±1·7†
Steelmaking	Rail steel 0·75%C, 0·8%Mn	Derge *et al.*[34]	54	0 – 3·2	±1·7
Steelmaking	Unspecified	Shields *et al.*[26]	20	5·7– 8·0	±1·3
Steelmaking	Basic electric range of carbon steels	Sykes *et al.*[28]	92	3·2–10·4	±2·1
Laboratory melts under He/H atmospheres	Armco iron	Carney *et al.*[18]	30	5·2–12·5	±0·72
Electrocharging	SAE 1020	Taiji Toh and W. M. Baldwin jun.[2]	4	2·1– 9·6	±7·8‡
Electrocharging	SAE 1020	Seabrook *et al.*[11]	15	3·3–15·9	±4·6
Pickling	SAE 1020	Darken and Smith§[8]	10	1·5–17·0	±1·5
Pickling	SAE 1020	Carney *et al.*[10]	4	5·0– 5·3	±0·3‡
Pickling	Armco iron	Carney *et al.*[10]	4	2·4– 2·8	±0·3‡
Pickling	Mild steel	Present work	42	0·8– 7·0	±3·0

* When samples are taken from a single heat or charged under identical conditions, the scatter expresses the deviation from the mean. When several heats are grouped the scatter indicates variations within groups. Where specimens were pickled or electrocharged for various times, the scatter indicates the deviation of the experimental points from the best curve of H_2 *v.* $\sqrt{t}$.

† Scatter estimated from a graph of H_2 *v.* humidity of atmosphere.

‡ With only four experimental values a scatter band of $\pm 2\sigma$ extends over less than 90% of all possible values.

§ Gas evolution at 170°C.

TABLE IV Samples re-analysed without further pickling

Sample no.	Type of steel	Total gas	Hydrogen	Treatment before analysis	Pickling treatment before first analysis
132 (a)	Cyanided	0·46	Nil	Water washed	8 h
229 (a)	Cyanided	0·55	Not est.	Immersed in ammonium persulphate and water washed	
229 (a) (3rd time)	Cyanided	2·37	0·35	Immersed in ammonium persulphate and water washed	3 min HCl+MnS
229 (a) (4th time)	Cyanided	1·27	Nil	Immersed in ammonium persulphate and water washed	
307 (a)*	En1a	0·36	Nil	Stored 24 h at −78°C Not water washed	30 min
307 (a)* (3rd time)	En1a	...	0·22	Washed in CCl_4	
307 (b)	En1a	0·88	0·28	Stored 100 h at −78°C Not water washed	30 min
307 (b)* (3rd time)	En1a	...	0·08	Washed in CCl_4	
305*	En1a	...	0·22	Washed in CCl_4	30 min

* Analysed at BCIRA

the fluctuations in hydrogen content caused by erratic losses in the bend test, by a fictitious increase in hydrogen content due to adsorption of moisture, or by loss of hydrogen during washing and drying of pickled specimens.

PLASTIC DEFORMATION IN THE BEND TEST

When hydrogen-charged specimens are deformed at room temperature some hydrogen is evolved almost instantaneously at the yield point.[20,21] In the bend test the middle portion of the specimens is severely deformed and it seemed desirable to estimate the loss.

Standard mild steel specimens were cut up into shorter pieces, ground or filed flat at the ends, pickled for 30 min, and analysed immediately; a large number of results on similar specimens broken in the bend test was available for comparison. Unpickled mild steel specimens did not break in the bend test, but were normally bent as far as the jig would allow and then fractured in the vice; a few unpickled specimens were cut into shorter pieces without bending and analysed. The results are compared in Table III.

The unpickled specimens gave similar analysis results whether they were broken or cut to short lengths. Specimens pickled for 30 min show rather greater variations. The cut specimens yielded more hydrogen and appreciably more of other gases than the broken ones. This is consistent with possible loss of hydrogen in the bend test, but the difference in hydrogen contents is not significant and the variation in impurity contents is significant only at the 10% level.

MOISTURE ADSORPTION

It has been suggested[8] that moisture adsorbed on the surface of steel specimens may react with iron or carbon during vacuum extraction, yielding fictitious hydrogen contents and solid or gaseous oxidation products. The preparation of specimens for analysis was governed mainly by speed, and may not have ensured the removal of the last traces of moisture. The surface condition of specimens after analysis, and gas yields of degassed specimens subjected to a second vacuum extraction after exposure to air, are therefore relevant.

Some specimens of mild steel and free-cutting steel, hydrogen charged by prolonged pickling to levels in excess of 15 ml/100 g, were covered with an adherent mercury coating on removal from the apparatus. This suggests that the specimens had been completely freed from passivating films during hydrogen extraction[22]; other specimens, which left the apparatus apparently clean but unwetted by liquid mercury, must have had some surface impurities. These may have had their origin in a reaction between iron and water vapour, or in the adsorption of oxygen on the surface of the pickled specimens. Clearly a considerable amount of hydrogen must be evolved at the surface before the passivating film is completely reduced.

In one isolated instance a mild steel specimen that had been pickled in cold 50% HCl for a week, was covered with an oxide layer after removal from the analysis apparatus; it gave a hydrogen figure of 343·5 ml/100 g and a figure for gaseous impurities of 37·7 ml/100 g. The curve of hydrogen content against pickling time suggests saturation at a hydrogen level of about 27 ml/100 g although appreciably higher contents were obtained in some instances. It seems likely that in this case adsorbed moisture had reacted with the steel during vacuum extraction at 700°C; the amount of FeO formed in a reaction yielding 300 ml/100 g of hydrogen would form a surface film about 1μ thick.

Both moisture and oxygen may be adsorbed at surfaces, activated by pickling or by heating in a vacuum, on exposure to air at room temperature. Darken and Smith[8] extracted the gases from a clean specimen at 600°C, exposed it to air and repeated the vacuum extraction; in four extractions, the average yield was 0·466 ml/100 g. In the present work there have been a few occasions when a specimen has been stored for some time after gas extraction and has then been subjected to another analysis without hydrogen charging; the gas yield should correspond to the products of reaction between adsorbed moisture or oxygen and the various elements in the steel. The results are summarized in Table IV. The hydrogen yields were lower than those of Darken and Smith in all cases, irrespective of the method of washing and drying employed.

Surface adsorption and contamination are somewhat worse when the surface is roughened. This is shown most clearly by analysis results on small specimens which had been cut from longer ones, leaving the saw-cut ends rough. Four unpickled specimens had mean contents of 2·40 ml hydrogen/100 g and 6·79 ml of other gases/100 g. Comparison with the corresponding figures for broken or cut and ground specimens in Table III shows an appreciable increase in gas yields due to the rough surface at the ends. The same applies to analysis results on five such saw-cut specimens pickled for 30 min; the mean hydrogen content was

TABLE V Effect of variations in washing and drying technique on hydrogen content

Washing and drying technique	Type of steel	Pickling time	Bend test Strain, cm	Load, tons	Gas analysis Hydrogen, ml/100 g	Impurities, ml/100 g
Normal (washed and wiped)	Notched specimen (0·4%S)	30 min	0·10	0·31	2·57	0·93
Normal (washed and wiped)	Mild steel	3 h	0·41	0·425	6·44	2·61
Washed and dried in hot air	Mild steel	3 h	0·44	0·41	25·5	2·7
Wiped on cloth	Mild steel	3 h	0·40	0·40	8·04	12·36
Swilled in acetone	Notched specimen (0·4%S)	30 min	0·08	0·32	2·2	1·5
Swilled in acetone	Mild steel	3 h	0·34	0·43	4·50	26·60
Dipped in dewatering fluid and dried in air	Mild steel	3 h	0·37	0·47	2·70	3·80
Dipped in dewatering fluid and wiped on cloth	Mild steel	3 h	0·41	0·51	11·42	8·48
Normal (washed and wiped)	Silver steel	3 min	0·31	0·91	0·13	1·03
Wiped on cloth	Silver steel	3 min	0·28	1·06	0·10	1·59

5·10 ml/100 g, the mean content of other gas 5·62 ml/100 g. Very severe surface roughening seems capable of increasing contamination of the specimen sufficiently to raise yields by 1–2 ml/100 g (compare ref.6).

Darken and Smith[8] also analysed the gas evolved at 600 C in the adsorption experiments and found that they contained between 42 and 56% hydrogen. Most other investigators[12,23] believe that the gas should consist predominantly of hydrogen. In our own experiments, considerable quantities of gases other than hydrogen have been detected, and in some cases this may be due to reaction with adsorption films.

Evidently, there is a strong possibility that some inaccuracies and fluctuations of hydrogen contents obtained in this work were due to moisture adsorption on the specimens, but, except in isolated instances which are easily recognized, the amount of hydrogen from this source is not likely to be an appreciable fraction of the hydrogen evolved from pickled specimens, for several reasons. About half an hour is required for the specimen to reach the extraction temperature, and there should be ample opportunity for adsorbed moisture to evaporate from the surface at low temperatures before the specimen is hot enough for reactions to occur between adsorption films and the steel. Secondly, the amount of hydrogen and other gases evolved from pickled specimens is greatly in excess of the values associated with adsorption films in Table IV or in the experiments of Darken and Smith.[8] Surface roughening due to pickling may increase adsorption, but in most steels the hydrogen content increased proportionately to the square root of the pickling time and this points to absorption of hydrogen by the steel rather than adsorption of moisture at the surface. The content of gases other than hydrogen, which is rather high, like that found in the reaction products of adsorption films,[8] was found to increase with the hydrogen content and to bear the same relation to pickling time.

It can be concluded that moisture adsorption makes a small contribution to the scatter of analysis figures, particularly at low hydrogen contents, but plays only a minor part in the gas evolution from specimens pickled for long periods.

PREPARATION OF SPECIMENS

Bastien[24] and Harvey[25] have found, in experiments on the effect of environment on the rate of recovery of ductility (which is presumably related to the loss of hydrogen from the steel), that recovery is faster in moist than in dry air, and faster in conductive water than distilled water. This observation suggested that some hydrogen might be lost from specimens during washing and drying. A few experiments to assess the probable magnitude of this loss and the possibility of reducing moisture adsorption and other contamination of the surface were made.

It was established by re-analysis that the normal method of washing and wiping on a cloth, followed by successive immersions in acetone and ether, did not introduce hydrogen; a small amount of gas was evolved but it contained no hydrogen. In other experiments, different methods of cleaning and drying were tried; one specimen was washed and then dried in a current of hot air; with others the wash was omitted and the acid was removed from the specimen by wiping with a cloth, swilling in acetone, or immersion in a dewatering fluid,* followed by wiping on a cloth or drying in a stream of air.

The results, in Table V, show erratic variations in hydrogen content unrelated to modified washing.

EFFECT OF SULPHIDE INCLUSIONS

As detailed examination of the experimental technique has not revealed the main source of the scatter of analysis results it may reasonably be supposed that there is a genuine variation in the amount of hydrogen absorbed by different specimens of the same steel under similar charging conditions. This conclusion is supported by the fact that the scatter increases, though not proportionately, with charging time and with gas content. A consideration of abnormally high gas contents that were sometimes obtained in routine pickling experiments led to the comparison of results given in Table VI. Although the contents of both hydrogen and other gases are quite anomalously high, the bend test results are quite consistent with those obtained on specimens exhibiting normal gas absorption. This suggests that it is the saturation concentration at the surface, and not the diffusion of hydrogen into the steel, which has been modified.

In an attempt to find the source of this variability, the acid in which cyanided specimens of screw wire had been pickled was kept until the gas analysis was completed. The acid from specimens yielding normal gas contents was transferred to one bottle, and the pickling solution that had been used for specimens of anomalously high gas yield was collected in another.

* Wakefield Dick. Industrial Lubricants, Dewatering Fluid No. 20.

TABLE VI Abnormally high gas contents

High values				Normal values			
Pickling time	Breaking Load, tons	Gas analysis Hydrogen, ml/100 g	Impurities, ml/100 g	Pickling time	Breaking Load, tons	Gas analysis Hydrogen, ml/100 g	Impurities, ml/100 g
En 1, plain							
30 min	Not broken	8·6	19·7	30 min	Not broken	3·2	3·9
		9·55	13·77				
		8·9	7·4				
		10·4	11·9				
		11·11	16·46				
		13·92	10·34				
8 h	0·42	20·05	16·05	8 h	0·43	7·6	8·8
77 h	...	59·3	59·7	77 h	...	26·0	25·0
14 days	...	167·1	200·0	14 days	0·425	27·0	26·0
Silver steel, plain							
3 h 10 min	0·80	3·17	1·16	3 h 10 min	0·8	0·90	0·96
20 h	...	8·40	10·60	20 h	0·75	3·0	2·8
	0·875	13·4	19·0				
	0·925	11·3	15·6				
Silver steel, notched							
8 h	0·45	3·68	1·82	8 h	0·40	1·75	1·65
Screw wire, cyanided, notched							
3 min	0·39	4·05	4·72	3 min	0·45	0·15	0·60
30 min	0·475	...	...	30 min	0·45	0·30	0·60
8 h	0·465	7·93	1·32	8 h	0·45	2·0	0·68
Screw wire, neutral salt bath, notched		Total ml/100 g				Total ml/100 g	
1 h 16 min	0·44	5·2		1 h 16 min	0·40	1·9	
3 h 10 min	0·50	20·4		3 h 10 min	0·40	2·5	
8 h	0·40	8·03		8 h	0·40	3·5	

The two solutions were subjected to chemical analysis. The only significant difference between the two solutions was a higher manganese content in the one corresponding to high gas yields. It is suggested that this manganese originates in manganese sulphide, which is decomposed in pickling; the sulphur is probably lost as H_2S. It was inferred that the abnormally high contents of hydrogen and other gases are associated with sulphur in the steel, and this is confirmed by the enhanced gas absorption of the high-sulphur free-cutting steel (cf. Tables I, VII, and VIII) compared with mild steel: after pickling for 8 h the hydrogen contents of the two steels are 39 and 9·2 ml/100 g respectively.

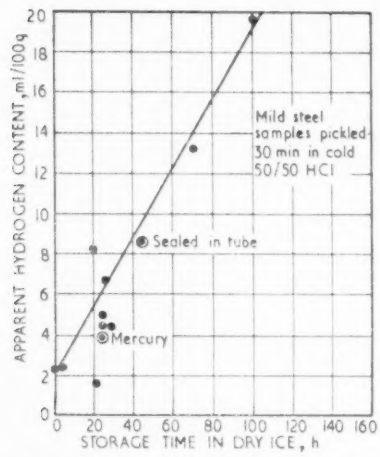
Since the sharp differences in gas absorption exemplified in Table VI were found in specimens from the same batch, they could not be attributed to major fluctuations in overall sulphur content. Instead, local fluctuations of sulphur distribution at the surface of the steel, where it is in direct contact with the pickling solution, must be responsible for the variability of gas absorption. The presence of an unusually coarse sulphide inclusion, or of an unusually large number of small ones, at the surface of the specimen may cause abnormal gas absorption. In the absence of segregation effects, the amount of sulphur in the surface, as in any random plane through the bulk of the steel, should be representative of the overall sulphur content, so that the variation should be no greater than that between different specimens from the same batch. Presumably, a histogram of the frequency of occurrence of sulphur levels or the particle size of sulphur inclusions in different specimens or in surfaces exposed at different times would show a normal distribution, with a mean corresponding to the overall sulphur content. Thus there may be a small but definite incidence of unusually high sulphur contents. The gas contents of specimens exhibiting unusually high gas absorptions show fluctuations considerably in excess of the random scatter of the 'normal' values; this suggests that the normal range is associated with an amount of sulphide in the surface layer not far in excess of the mean and that beyond this threshold gas absorption increases steeply with sulphide content.

Some specimens with high gas contents were pickled again after analysis and did not, apparently, absorb unusual quantities of gas. Evidently the sulphide inclusions have been dissolved out of the surface in the first pickling treatment, so that the chance of a high surface sulphide content in the second pickle is no greater in specimens showing high gas absorption after the first pickle than in 'normal' ones. It has been found, however, that anomalous gas absorption occurs more frequently in specimens that have been pickled for long periods. This is probably due to penetration of some part of the surface exposed by prolonged pickling to the core of the rimming steel where the content is higher, i.e. to the intervention of segregation effects.

It is concluded that sulphide inclusions exposed to reaction with the pickling solution have a profound effect on hydrogen absorption. The amount of sulphide so exposed varies in a random manner and therefore imposes a substantial random fluctuation on the hydrogen analysis results.

STORAGE OF SPECIMENS BEFORE ANALYSIS

It is not always possible to carry out a hydrogen analysis immediately after pickling. When it is desired to analyse both halves of a broken specimen, the time taken for the analysis of the first (several hours) is long enough to permit a considerable loss of hydrogen from the second, if it is held at room temperature. In one experiment a large number of coil spring specimens was pickled and plated in the works,[13] the loss of ductility was measured on all specimens, and it was intended to analyse selected specimens for hydrogen. It was obviously necessary to store the specimens between pickling and analysis; it was known that prolonged storage at room temperature could lead to appreciable losses of hydrogen but that specimens can be stored for as long as six days in a solid CO_2-acetone bath without loss of hydrogen.[27] The specimens were


APPARENT HYDROGEN CONTENT, ml/100g
STORAGE TIME IN DRY ICE, h
Mild steel samples pickled 30 min in cold 50/50 HCl
Sealed in tube
Mercury

2 *Effect on hydrogen yield of time of storage in dry ice*

stored in a large Dewar's vessel together with large pieces of solid CO_2. Experiments showed a substantial increase in the yield of hydrogen in vacuum annealing at 700°C with prolonged storage in solid CO_2. This extremely surprising result has been confirmed on many mild steel specimens, but not on all, and on one specimen of pure iron; it has not been reproduced with other steels used in the experiments. In Fig.2 hydrogen yield is plotted against storage time. In order to eliminate any contamination or surface effects, one specimen was sealed into an evacuated glass capsule before storage; the analysis result for this specimen is indicated in Fig.2 and fits on the straight line. One specimen was held at room temperature under mercury for some time, a procedure which is known to delay the loss of hydrogen[27]; the corresponding point in Fig.2 suggests that there is an increase in hydrogen yield in this case also, although the point is considerably below the line for storage at −78°C. The effect of holding under mercury has been confirmed; Table V gives an example, also confirmed by others not quoted, of a pronounced increase in yield for specimens dried in warm air. It is possible that susceptible specimens will show this effect over a range of storage temperatures, although the influence of time will no doubt vary with the temperature.

These extremely puzzling observations are the subject of further studies. Only the most tentative explanation can be offered at this stage. It is generally accepted that hydrogen can be present in steel in at least two forms, that there are two rates of diffusion,[28,29,30] and that there are substantial differences in the kinetics of outgassing, the reasons for which are not fully understood.[31,32] In order to explain the 'storage effect' it must be postulated that in the period after hydrogen charging there can be a gradual change in the absorption of the bulk of the hydrogen in the lattice, perhaps by collecting on dislocations or precipitating at gross discontinuities or interfaces, so that it is less readily extracted by vacuum annealing at 700°C. The experimental observations to date can be accounted for, if gradual heating in the analysis apparatus puts the hydrogen into the less readily extracted condition, while storage at −78°C, or at room temperature under mercury, or a very short exposure to a warm air stream, favour the more readily extractable hydrogen.

GAS EVOLUTION AT DIFFERENT TEMPERATURES

It is widely accepted[12] that practically all the hydrogen present in steel is evolved in vacuum extraction at 600–700°C, but there have been a few observations of substantial proportions being evolved on subsequent heating[32] and some claims that the bulk of the hydrogen is in fact evolved at room temperature, at 170°C,[8] or at 400°C.[5] It was not the purpose of this investigation to resolve these contradictions, but a few experiments were carried out with a view to establishing the optimum extraction temperature for the

TABLE VII Gas evolution at different temperatures

Sample no.	Type of steel*	Storage before analysis	Temperature, °C	Time	Gas evolution: Total gas, ml/100 g	Hydrogen ml/100 g	Hydrogen % of aggregate	Impurities ml/100 g	Impurities % of aggregate
346 (a)	Mild steel, En1	...	Room	¾ h	0·316	0·230	8·89	0·086	4·11
			700°C	5 h	4·37	2·36	91·11	2·01	95·89
346 (b)	Mild steel, En1	24 h at −78°C	Room	35 min	0·27	nil	0	0·27	14·35
			700°C	4 h	3·14	1·53	100	1·61	85·65
344 (a)	Free cutting, En1a	...	Room	19 h	5·40	4·78	...	0·62	...
			700°C	3 h	3·46	n.d.	...	...	...
344 (b)	Free cutting, En1a	48 h at −78°C	Room	7½ h	5·12	4·39	65·4	0·73	15·6
			700°C	4 h	6·28	2·32	34·6	3·96	84·4
321 (a)	Free cutting, En1a	...	100°C	6½ h	1·31	1·14	32·9	0·17	5·38
			200°C	1½ h	nil	nil	0	nil	0
			300°C	2½ h	0·26	0·12	3·46	0·14	4·33
			400°C	1 h 50 min	0·68	0·33	9·55	0·35	11·09
			500°C	1½ h	0·81	0·16	4·62	0·75	23·78
			600°C	11 h 40 min	2·08	1·04	30·05	1·04	32·9
			700°C	3 h	1·38	0·67	19·4	0·71	22·45
321 (b)	Free cutting, En1a	216 h at −78°C	100°C	3½ h	1·68	1·39	48·2	0·29	11·20
			200°C	1 h 50 min	nil	nil	0	nil	0
			300°C	2½ h	0·46	0·14	4·85	0·32	12·38
			400°C	4 h	0·40	nil	0	0·40	15·46
			500°C	3½ h	0·72	0·30	10·41	0·42	16·25
			600°C	7½ h	1·43	0·72	25·0	0·71	27·41
			700°C	4 h	0·78	0·33	11·45	0·45	17·40
348 (a)	Silver steel (cold worked)	...	Room	63 h	1·85	1·21	62·1	0·64	33·0
			700°C	4½ h	2·04	0·74	37·9	1·30	67·0
348 (b)	Silver steel (cold worked)	70 h at −78°C	Room	17½ h	1·68	1·52	85·85	0·16	9·75
			700°C	4 h	1·74	0·25	14·15	1·49	90·25

* All specimens pickled for 30 min in 50% HCl

TABLE VIII Hydrogen evolution at temperatures above 700°C

Sample no.	Type of steel	Previous treatment	Apparatus	Hydrogen evolution: Yield at 700°C ml/100 g	BCIRA Higher temperature Temperature, °C	BCIRA Higher temperature ml/100 g	Vacuum fusion ml/100 g
307 (a)	En1	30-min pickle	GKN	3·6	1100	0·27	0·50
307 (b)	En1	30-min pickle	GKN	3·88	1100	0·09	
305 (a)	En1	30-min pickle	GKN	3·21	1100	0·22	0·55
305 (b)	En1	30-min pickle + 20 h at −78°C	GKN	8·22			0·89
—	En1	30-min pickle + 20 h at −78°C	BCIRA	0·46	1070	0·17	
—	En1	30-min pickle + 20 h at −78°C	BCIRA	0·75	1070	0·59	
—	En1	Machined all over	BCIRA	0·12	1070	0·02	
—	En1	Machined all over	BCIRA	0·08	1070	0·007	
—	En1	30-min pickle	BCIRA	2·42	1070	0·03	
—	En1	30-min pickle	BCIRA	2·20	1070	0·16	
—	En1	30-min pickle + 4 days at −78°C	BCIRA	2·41	1070	0·02	
—	En1	30-min pickle + 4 days at −78°C	BCIRA	2·19	1070	0·09	
339 (a)	En1a	30-min pickle	BCIRA	6·15	950	0·22	
341 (a)	En1a	30-min pickle + 8 days at −78°C	BCIRA	4·25	950	0·08	

analysis of the type of specimens used in the pickling experiments.

The analysis apparatus used in this investigation is designed for a maximum temperature of 700°C. Gas evolution at room temperature and at 700°C was compared on specimens of different steels after pickling for 30 min in cold 50% HCl. A steel which yielded a fair proportion of its hydrogen at room temperature, the high-sulphur free-cutting steel En1a, was chosen for an experiment in which the gases were extracted at progressively rising temperatures; when gas evolution was complete at one temperature, i.e. when no further gas was evolved in at least half an hour, the temperature was raised by 100°C. Both halves of the broken specimen were used for these analyses, one immediately after pickling and breaking, the other after some storage at −78°C; no consistent storage effect was detected in these specimens.

The results are presented in Table VII. Evidently, no hydrogen to speak of was evolved from the mild steel at room temperature, while the other steels yielded substantial proportions of their hydrogen. In all cases, considerable amounts of hydrogen were retained until the temperature was raised to 600° and 700°C. (Recovery of ductility in baking is not inconsistent with the retention of some hydrogen and has been shown to be favoured by the redistribution of hydrogen over the section of the steel.[13]) The proportion of gaseous impurities evolved at room temperature is much smaller than the proportional hydrogen yield; the bulk of the impurities comes off above 500°C. Presumably, surface reactions between hydrogen, traces of oxide, carbide, and other elements in the steel, can only take place at higher temperatures.

By the courtesy of the British Cast Iron Research Association it was possible to carry out a few experiments with vacuum annealing at temperatures up to 1100°C and three vacuum fusion analyses. Some specimens previously analysed and outgassed at 700°C were reheated to higher temperatures, or fused under vacuum at BCIRA; others were pickled and analysed there. Their apparatus estimates hydrogen content only; no figures for gaseous impurities are given in Table VIII where the results are collected.

The vacuum fusion results indicate that not all the hydrogen is evolved in vacuum extraction at 700°C; the amount retained increases, but represents a smaller proportion, as the total hydrogen content increases. Less than 10% of the hydrogen is evolved in vacuum annealing above 700°C, except for 'as received' specimens affected by surface contamination and adsorption. Evidently, vacuum analysis at 700°C yields figures that are fairly representative of the hydrogen content, but a small amount of hydrogen is retained by the steel.

SUMMARY

A routine has been developed for hydrogen analysis and ductility testing of pickled specimens. The scatter of results is appreciable and is due partly to adsorption of moisture at the surface but predominantly to genuine variations in gas absorption under similar conditions. One reason why gas absorption varies is that the hydrogen concentration of the steel surface in equilibrium with the pickling solution is influenced by the sulphide inclusions exposed to the action of this solution; the amount and particle size of sulphide so exposed is subject to some random scatter.

Methods of washing and drying were examined and the most satisfactory technique has been adopted for routine analysis. Specimens must be analysed as soon as possible after they are charged with hydrogen; storage in air involves loss of hydrogen, storage at low temperatures leads in some cases to an unexplained increase in the yield of hydrogen.

Experiments have shown that some hydrogen may be evolved from pickled specimens at room temperature but a considerable amount is retained to 600°C and some to 700°C. Further rise in temperature results in a slight increase in hydrogen yield and an additional amount, about 10% of the total, is evolved only by vacuum fusion. The gas evolved at 700°C contains a considerable proportion of gases other than hydrogen.

ACKNOWLEDGMENTS

Acknowledgments are due to the British Cast Iron Research Association and particularly to Mr L. W. L. Smith for carrying out analyses of pickled specimens in their apparatus. The authors are also indebted to Dr T. Emmerson, Director of Research, GKN Group Research Laboratory, for permission to publish this paper.

REFERENCES

1. F. Eisenkolb and G. Ehrlich: *Arch. Eisenhüt.*, 1954, **25**, (3/4), 187–194.
2. Taiji Toh and W. M. Baldwin, jun.: in 'Stress corrosion

cracking and embrittlement', 176–186; 1956, London, Chapman and Hall.
3. L. D. McGraw, *et al.*: *NACA*, TN 2696, April, 1952.
4. L. D. McGraw, *et al.*: *ibid.*, TN 3164, March, 1954.
5. F. Körber and H. Ploum: *Mitt. Kaiser-Wilh-Inst.*, 1932, **14,** 229–248.
6. F. Cooke and F. E. A. Shanahan: *J. Appl. Chem.*, 1957, **7,** (7), 388–392.
7. S. Besnard and J. Talbot: *Rev. Mét.*, 1959, **56,** (2), 163–170.
8. L. S. Darken and R. P. Smith: *Corrosion*, 1949, **5,** (1), 1–16.
9. R. M. Hudson, *et al.*: *ibid.*, 1960, **16,** (3), 97–100.
10. D. J. Carney, *et al.*: *Trans. AIME*, **188,** *J. Metals*, Feb. 1950, 397–403.
11. J. B. Seabrook, *et al.*: *ibid.*, **188,** *J. Metals*, Nov. 1950, 1317–1321.
12. W. C. Newell: *JISI*, 1940, (I), 243P–253P; *ibid.*, 1943, (II), 278P and 287P.
13. K. Sachs and S. H. Melbourne: *Trans. Inst. Met. Finishing*, 1959, **36,** 142–152.
14. P. D. Blake: *Brit. Weld. J.*, 1958, **5,** (12), 565–567.
15. J. H. Andrew, *et al.*: *JISI*, 1950, **165,** 382–389.
16. H. Schumann and F. Erdmann-Jesnitzer: *Arch. Eisenhüt.*, 1953, **24,** (7/8), 353–360.
17. P. D. Blake: *Brit. Weld. J.*, 1958, **5,** (3), 126–129.
18. D. J. Carney, *et al.*: *Trans. AIME*, **188,** *J. Metals*, Feb. 1950, 404–413.
19. P. D. Blake: *Brit. Weld. J.*, 1957, **4,** (3), 146–154.
20. F. A. Zappfe: *JISI*, 1946, **154,** 123P–130P.
21. F. Erdmann-Jesnitzer: *Arch. Eisenhüt.*, 1957, **28,** (5/6), 355–365.
22. Liquid Metals Handbook, Atomic Energy Commission, June 1952, 124; also D. J. Wright: *Proc. Phys. Soc. B*, **68,** (425B), Pt 5, 297; and T. P. Hoar and T. W. Farthing: *Nature*, 1952, **169,** 324–325.
23. E. Piper, *et al.*: *Stahl Eisen*, 1953, **73,** 817–828.
24. P. Bastien: *Rev. Mét.*, 1941, **38,** (9), 225–238; *ibid.*, 1941, **38,** (11), 272–284.
25. G. Harvey: unpublished work.
26. B. M. Shields: *Trans. AIME*, **197,** *J. Metals*, Feb. 1953, 180–184.
27. B. B. Bach, *et al.*: *J. Res. Dev., BCIRA*; 1954, **5,** 490; *JISI*, 1954, **176,** 257–263.
28. C. Sykes, *et al.*: *JISI*, 1947, **156,** 155–180.
29. J. D. Hobson: 1958, **189,** 315–321.
30. C. R. Frank, *et al.*: *J. Appl. Phys.*, 1958, **29,** 892–898.
31. A. Demarez, *et al.*: *Acta Met.*, 1954, **2,** (2), 214–223.
32. E. W. Johnson and M. L. Hill: *Acta Met.*, 1955, **3,** (1), 99–101.
33. J. D. Hobson and J. R. Rait: Unpublished work (BISRA Restricted Report No. SM/C/23/55).
34. G. Derge, *et al.*: *Trans. AIME*, Metals Technology, June 1948, TP 23621–28.

The bearing properties of 1%C–Cr steel as influenced by steelmaking practice

R. F. Johnson and J. F. Sewell

INTRODUCTION

BETTER STEEL QUALITY is being demanded as one of the factors in improving the service performance of bearings. In achieving this the steelmaker faces the problem of assessing the effects of changes in his practice on quality requirements which cannot, as yet, be precisely defined. A bearing manufacturer, though he often includes an inclusion standard in his specification, bases his judgment of quality ultimately on the results of a bearing fatigue test. In this, usually 30 tests are run on a standard bearing in a rig under overload conditions to obtain completion of the test in reasonable time. From the steelmaker's point of view such private information loses much of its value owing to the length of time (months) which lapses between steelmaking and assessment. A further difficulty is that the conditions of the test vary from bearing manufacturer to bearing manufacturer and it has never been established that results from different tests are comparable. Published information[1–5] on the properties of 1%C–Cr bearing steel, heat-treated to a hardness of 750 DPN, is mainly confined to the results of rotary bending fatigue tests and these show a wide range of properties. Attempts to find a reliable relationship between these bearing tests and the simpler rotary bending fatigue tests have not, so far, shown a lot of success.

Manuscript received 2 June 1960.
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SYNOPSIS

A fatigue rig, which simulates in simple form the conditions applying in the case of bearing endurance tests and produces the same type of failures, has been developed. Tests have been carried out on standard 1%C–Cr quality steel to explore the effect of different steelmaking procedures and, in the case of basic electric arc steels, the effect of deoxidation practice on the performance of the material. The rig test results are compared with data obtained from rotary bending tests and standard bearing tests. Considerable success has been achieved in correlating rig test performance with the inclusion content of the material, provided that a special counting technique is used; no indication of the performance, however, is obtained from standard methods. 1864

In this work a new form of fatigue test has been investigated which is designed to simulate the bearing test in simple form and to produce failures of the same type that occur in bearings. An outline of this equipment was given by Bardgett[6] in the discussion on a paper by Frith.[7] A start has already been made on a comprehensive series of tests covering various modifications in steelmaking practice. Results are presented of tests on ten basic electric arc casts, two acid OH casts, one special OH cast described by Frith as 'neutral open-hearth' steel, and three high-frequency vacuum-melted casts. Conventional rotary bending fatigue tests have also been carried out on most of these steels and these have led to the suggestion that, under specific conditions of testing, a relationship may exist between the two tests. In the case of five of the basic electric arc casts, bearing manufacturers' tests are also reported and compared. It would be unrealistic to draw any firm conclusions from the results of so few casts but the amount of interesting information obtained seems worth recording and appraising for the trends it indicates.

In an attempt to explain the differences in fatigue lives between different steels obtained on the experimental fatigue rig, a detailed metallurgical examination of the test specimens has been carried out. As the work has progressed attention has been concentrated on metallographic identification and assessment of the non-metallic inclusions in the neighbourhood of the failures. This work has produced fascinating speculations warranting further study. If it is confirmed that the effects of different types of inclusions on fatigue life vary according to the stress level, then the value of overload tests becomes extremely doubtful. Such studies may well lead to the production of steels which will give improved and more consistent results in tests without bringing about a comparable improvement in the lives of bearings in service.

The need for a new approach to the study of the bearing properties of 1% C–Cr steel received practical recognition with the commissioning of the first laboratory-type fatigue rig 5 years ago. The information it has yielded in the intervening years in conjunction with the parallel information from more conventional tests has not yet led to a positive understanding of how and why steel fails under bearing conditions, and has, if anything, emphasized the lack of knowledge. However, the challenge is stimulating greater efforts and facilities for laboratory rig testing are being increased several fold. No direct influence on steelmaking practice can yet be claimed although the greater awareness of the problems in production circles may well be having some effect. It is certainly true that during the past couple of years the bearing manufacturers have consistently reported, based on their various forms of examination of the hundreds of tons of electric-arc melted carbon–chromium steel that have passed through their hands, that quality is improving.

Steelmaking

Most of the 1%C–Cr ball-bearing steel is produced in basic electric arc furnaces and the aim of this work has been to discover ways of improving the quality of this steel. Of the ten casts of this quality tested on the fatigue rig, nine were produced in the authors' company and the steelmaking details are given in Table I. Six were made in 80-ton furnaces (BEA1, 2, 6, 7, 8, and 9) and three in 12½-ton furnaces (BEA3, 4 and 5).

The standard steelmaking procedure used as a basis to which modifications in technique have been applied, comprises an 80% scrap charge refined under the two-slag system. In the oxidizing stage the aim is to catch the carbon on the way down and after removal of the slag to deoxidize the bath with ferrosilicon. The second slag is formed by fluxing limestone with fluorspar and then working it into the white falling condition by the addition of crushed carbon. Ferrosilicon is the main deoxidant used in working the charge. This practice is represented by casts BEA1 and BEA2.

The 12½-ton furnaces were used to produce the initial experimental steels. Two casts (BEA3 and BEA4) were made in which the percentage cast iron in the charge was increased to obtain a more vigorous carbon boil and a special low-sulphur iron used to help in reducing the sulphur content to a maximum of 0·010% in the finished steel. The steelmaking practice for the third of the 12½-ton casts (BEA5) was essentially similar but specially selected scrap and a special iron were used in the charge to ensure a low level of incidental elements.

The next stage was to explore the effect of final deoxidation in the ladle with calcium silicide, on the basic standard practice. In the case of cast BEA6, 5 lb/ton was used but delays were experienced in the working of this cast, first through a broken electrode, and second through having to remove and remake the oxidizing slag in order to reduce the phosphorus to a satisfactory level. In casts BEA7 and BEA8 3¾ lb/ton of calcium silicide were used after a normal working of the charge apart from the use of less ferrosilicon during the final stages.

The last of the nine casts (BEA9) represents the first attempt to modify the deoxidation practice during the working of the charge. The object was to obtain a gaseous deoxidation of the bath after the oxidizing period by dipping the carbon electrodes. In approaching this practice cautiously, more ferrosilicon than had been intended was used at the same time so that the aim was only partially achieved. In addition, a small amount of aluminium (7 oz/ton) was used immediately the white falling slag had formed and the final deoxidation was made with 3¾ lb/ton of calcium silicide in the ladle. Casts on which a more complete gaseous deoxidation has been achieved will be tested later.

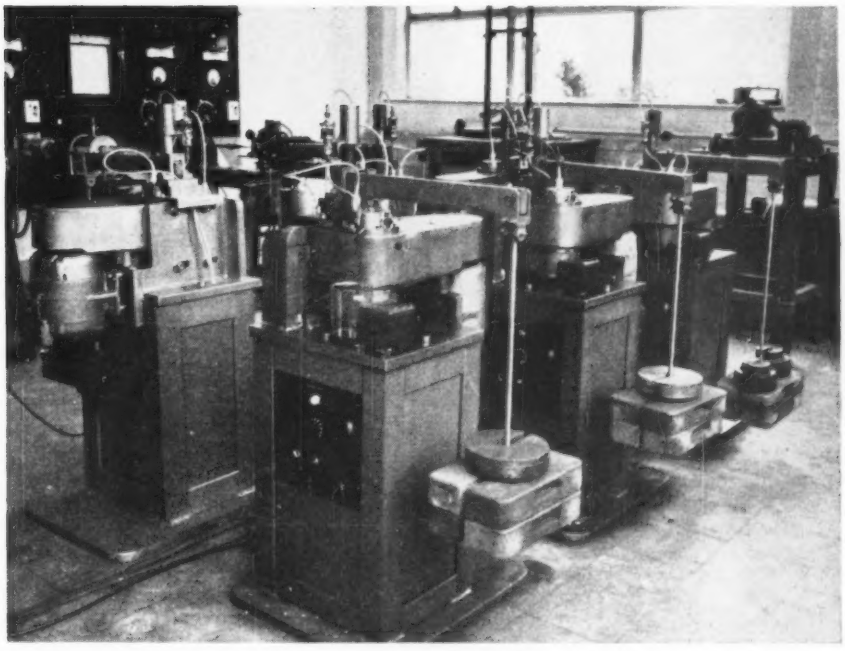
The tenth cast tested was one which had shown extraordinarily good results in the bearing manufacturers' fatigue tests and was made by English Steel Corporation. The information given in Table I has been provided by this firm. The steelmaking practice was similar in all details to that which has previously been described as standard practice in the author's works but the final ladle deoxidation was carried out with calcium–silicon–manganese alloy. For purposes of comparison this deoxidation practice has been grouped with the CaSi-deoxidized casts.

Apart from the basic electric arc casts, the three hf vacuum-melted casts (HFV1, 2, and 3) kindly provided by the Crucible Steel Company were included in the programme of testing in order to try to measure the value of this refinement to steelmaking techniques. No information on the melting practice is available.

The present programme of rig tests was completed

TABLE I Details of steelmaking practice, chemical analysis, and tests

Steelmaking practice	*Basic electric arc*												*Vacuum melted*			*Open-hearth*					
	Standard practice			Special low sulphur			Ladle deoxidation with calcium silicide				Electrodes dipped	As BEA1 with high Mn	High frequency			English acid		Swedish acid		Basic	'Neutral'
Cast	BEA1	BEA2	BEA12	BEA3	BEA4	BEA5	BEA6	BEA7	BEA8	BEA10	BEA9	BEA11	HFV1	HFV2	HFV3	AOH (E1)	AOH (E2)	AOH (S1)	AOH (S2)	BOH1	NOH1
Steelmaking																					
Furnace size, tons	80	80	65	12½	12½	12½	80	80	80	30	80	80	...	...	...	80	80	...	...	80	...
% Scrap in charge	83·5	78·0	91·0	73·0	73·0	77·0	76·0	80·0	77·0	...	77·0	75·0	...	...	...	...	...	...	...	...	...
Melt time, h	3·15	3·14	3·40	2·12	2·22	2·07	4·30	3·18	3·10	...	4·16	3·31	...	...	...	...	...	...	...	...	...
Oxidizing time, h	1·50	1·39	3·17	1·52	2·03	2·02	3·33	2·07	1·55	...	3·17	2·00	...	...	...	...	...	...	...	...	...
Reducing time, h	1·05	1·17	1·35	1·23	1·17	1·35	1·34	1·30	2·25	...	2·18	2·00	...	...	...	...	...	...	...	...	...
Total time, h	6·10	6·10	8·32	5·27	4·42	5·34	9·37	7·10	7·30	...	9·11	7·31	...	...	...	...	...	...	...	...	...
Deoxidation after slag	FeSi	FeSi	FeSi	FeSi	FeSi	FeSi	FeSi	FeSi	FeSi	...	Electrode FeSi FeMn	FeSi	...	...	...	...	...	...	...	...	...
2nd slag	W.F.	W.F.	W.F.	W.F.	W.F.	W.F.	W.F.	W.F.	W.F.	...	W.F.	W.F.	...	...	...	...	...	...	...	...	...
Melting carbon, %	1·23	1·17	0·81	1·69	1·69	1·40	1·28	1·18	1·40	...	1·25	1·15	...	...	...	...	...	...	...	...	...
2nd slag carbon, %	0·94	1·03	0·90	0·93	0·93	0·94	0·88	0·92	0·99	...	0·97	0·87	...	...	...	...	...	...	...	...	...
Melting sulphur, %	0·037	0·036	0·036	0·022	0·021	0·024	0·035	0·023	0·031	...	0·023	0·026	...	...	...	...	...	...	...	...	...
Final sulphur, %	0·014	0·025	0·020	0·007	0·009	0·008	0·020	0·015	0·020	...	0·010	0·009	...	...	...	...	...	...	...	...	...
Special deoxidants, lb/ton	...	...	...	...	...	...	5CaSi	3½CaSi	3¾CaSi	CaSiMn	⅝Al 3¾CaSi	3¾CaSi	...	...	...	...	...	...	...	...	...
Tapping temperature, °C	1560	1580	1580	1620	1620	1619	1590	1570	1570	...	1580	1580	...	...	...	...	...	...	...	...	...
Production																					
Ingot size, cwt	50	50	40	40	40	40	40	50	50	31	40	50	...	...	...	50	50 / 31	...	...	45	...
Rolled size, in. dia.	4	3½, 3¾, 4¼	5¼	6	6	6	4¼, 5¼	3¼, 4¼	4, 4½, 5¼	6½	4¼	5¾	...	...	...	4in²	3½in²	79·7 mm	85·1 mm	4in²	3¼
Chemical Analysis, %																					
C	1·00	0·98	0·99	1·03	1·03	0·99	1·03	0·98	0·98	1·02	1·02	1·00	1·03	1·03	0·97	1·05	1·02	0·96	0·99	1·04	1·03
Mn	0·38	0·35	0·32	0·31	0·32	0·32	0·29	0·30	0·35	0·29	0·32	0·99	0·36	0·36	0·40	0·64	0·46	0·32	0·33	0·51	0·49
Si	0·25	0·31	0·20	0·22	0·26	0·31	0·30	0·31	0·32	0·27	0·27	0·55	0·25	0·25	0·25	0·22	0·20	0·33	0·34	0·28	0·26
S	0·015	0·020	0·021	0·007	0·008	0·008	0·020	0·016	0·020	0·027	0·010	0·009	0·007	0·007	0·012	0·028	0·042	0·022	0·021	0·022	0·035
P	0·018	0·026	0·015	0·009	0·013	0·011	0·021	0·016	0·018	0·013	0·016	0·021	0·003	0·003	0·010	0·030	0·035	0·021	0·028	0·026	0·027
Ni	0·12	0·12	0·16	0·145	0·13	<0·02	0·12	0·20	0·15	0·20	0·11	0·14	<0·02	...	0·02	0·13	0·12	<0·02	0·03	0·10	0·19
Cr	1·42	1·43	1·36	1·37	1·39	1·41	1·43	1·39	1·38	1·33	1·42	1·01	1·52	1·50	1·57	1·58	1·34	1·60	1·51	1·49	1·38
Mo	<0·02	0·045	...	0·053	0·083	<0·02	<0·02	0·03	0·06	0·062	0·04	0·06	<0·02	0·03	<0·02	<0·02	0·07	<0·02	0·035	0·05	0·033
Tests																					
Tests completed R rig W Wohler B bearing	RW	RWB	B	R	R	R	RWB	RWB	RWB	RWB	RW	W	RW	RW	R	RW	W	RW	W	W	RW



1 *Battery of test rigs*

with two acid OH casts, one of English manufacture (AOH (E1)) and one of Swedish manufacture (AOH (S1)), and a 'neutral OH' cast of English manufacture (NOH1). These various modifications in steelmaking practice are summarized in Table I.

For the rotary bending fatigue tests samples from all these steels were used with the exception of the three 12½-ton casts and one vacuum-melted cast (HFV3). In addition tests were made on an 80-ton electric arc cast made to a specification calling for higher manganese and silicon content with a lower chromium (BEA11), two further acid OH casts, one English (AOH (E2)), and one Swedish (AOH (S2)), and one cast of basic OH quality (BOH1).

Bearing manufacturers' tests were confined to basic electric arc casts and results cover BEA2, BEA6, BEA7, BEA8, and BEA10. In addition a bearing test was conducted on another 80-ton basic electric arc cast (BEA12) which was made according to the standard procedure, but in this case no rig or rotary bending tests were done.

Chemical analysis

Details of the chemical analyses of all casts used in the investigation and the type of tests done on each cast are given in Table I. With the exception of cast BEA11 no cast varies significantly from the general range 0·95–1·05%C, 0·30–0·60%Mn, 1·30–1·60%Cr.

Forging and rolling

The material used for the different tests was:

(i) *Rig test* 3¼ in. dia. bar
(ii) *Rotary bending fatigue test* ¾ in. dia. bar
(iii) *Bearing tests* either
  (i) 4·034 in. o.d. × 3·084 in. i.d. tube rolled from 5 in. dia. bar
  (ii) 3·092–3·062 in. o.d. × 1·926–1·772 in. i.d. rolled from 4 in. dia. bar (outer race)
  (iii) 2·217–2·187 in. o.d. × 1·501–1·309 in. i.d. rolled from 3 in. dia. bar (inner race).

Production details e.g. ingot size and rolled size, where available, are given in Table I. These rolled sizes were converted into the test piece sizes as follows:

(i) for rig test, by hammer forging
(ii) for rotary bending test, by hammer forging to 2 in. square and then rolling to ¾ in. dia.
(iii) for bearing test, by standard tube production.

Heat treatment

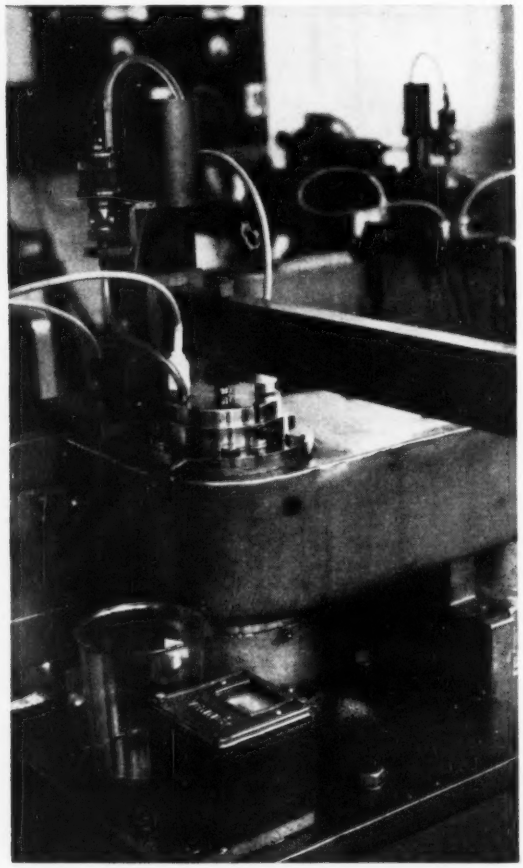
In all cases a standard heat treatment was adopted, the details of which are as follows:

(i) material softened by being heated in furnace to 790°C and soaked 4 h. Cooled at ½°C/min from 790° to 740°C and at 1°C/min from 740°C to room temperature.
(ii) hardened 850°C (½ h soak) oil-quenched
(iii) specimen allowed to stand for 2 days
(iv) soaked ¼ h at −78°C
(v) specimen allowed to stand a further 2 days
(vi) tempered 180–250°C (1 h) air cooled.

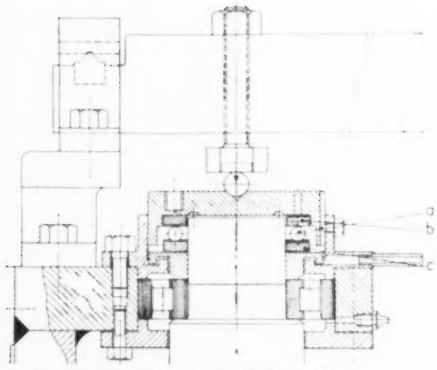
The hardness of the material after treatment ranged from 700 to 800 DPN.

Fatigue test rig

The aim in the development of a suitable test rig was to have a machine as simple as possible, consistent with providing a simulated bearing test. In addition, the test specimen employed should be of a form which could be readily machined, using standard machine tools. The design of the first rig to be completed was based on the suggestions of two of the leading bearing manufacturers in the UK. As a result of experience with the prototype machine certain modifications were carried out, aimed primarily at reducing the



2a *Test assembly*



a balls *b* test bearing *c* standard thrust race

2b *Sectional view of test bearing and housing*

amount of inherent vibration, and effecting improvements in the arrangement of the test bearing assembly to facilitate setting up, inspection and removal.

A general view of a battery of test rigs of the type at present being employed is shown in Fig.1, and a close-up of one of these machines is shown in Fig.2*a*. A sectional view of test bearing and housing is shown in Fig.2*b*. The machine consists essentially of a vertical spindle carried in a U-shaped bracket, the spindle being journalled on two roller bearings which take the load from a belt drive. The test (thrust) bearing is located at the upper end of the spindle and is mounted in a loose sliding housing which can readily be removed without disturbing the remaining bearings on the spindle. The test bearing is isolated from the adjacent roller bearing by means of a baffle, which prevents any debris from failed test races reaching the roller bearing.

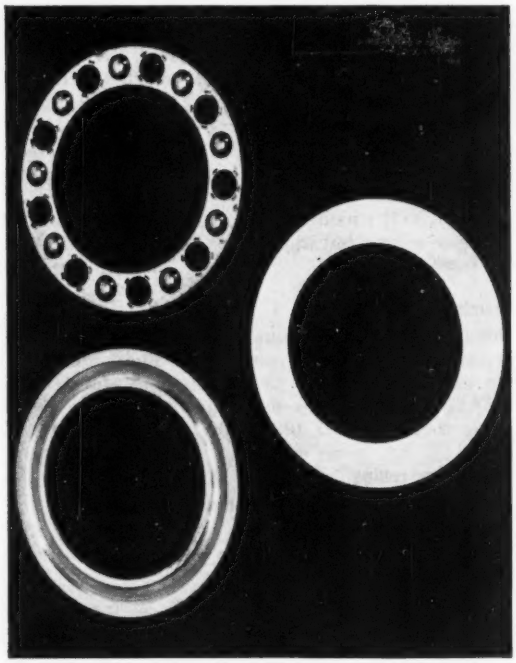
Load is applied to the test bearing through a lever system, the reaction being taken by a thrust bearing located at the lower end of the spindle. To ensure that the load is applied centrally to the test bearing, it is transmitted through a ball sunk into a centre hole in the test bearing housing.

Adequate lubrication is provided by means of an oil drip feed, which maintains a flow of light machine oil during the course of the test.

Test bearing

It is known that in standard bearings it is difficult to manufacture within the close tolerances necessary for the relatively thin hardened rings which are used and that the life of an individual bearing depends to some extent on the tolerance limits which are imposed. It was decided that these difficulties could be overcome and the requirements of a simple readily produced specimen met by adopting the form of a flat ring. Such a specimen also has the advantage that a smaller contact area is involved compared with a standard grooved race, and this has the effect of reducing the load that must be applied to obtain a given level of stress. Failure is thus confined to the test specimen and also the life of other bearings used in the construction of the rig is considerably increased.

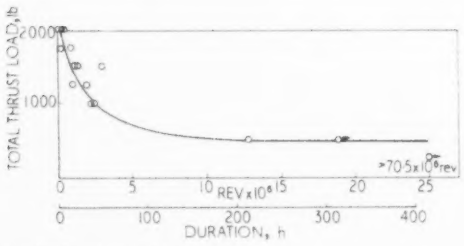
The test ring measures $2\frac{31}{32}$ in. o.d. $\times 2\frac{1}{32}$ in. i.d. $\times$ $\frac{7}{32}$ in. thick, and forms the top race of a standard



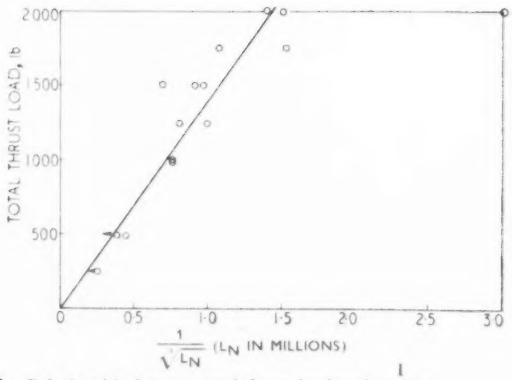
3 *Test bearing*

TABLE II Rig, bearing, and Wöhler test data

Steelmaking practice	*Basic electric arc*												*Vacuum melted*			*Open-hearth*						
	Standard practice			Special low sulphur			Ladle deoxidation with calcium silicide				Electrodes dipped	Standard with high Mn	High frequency			English acid		Swedish acid		Basic	'Neutral'
Cast	BEA1	BEA2	BEA12	BEA3	BEA4	BEA5	BEA6	BEA7	BEA8	BEA10	BEA9	BEA11	HFV1	HFV2	HFV3	AOH (E1)	AOH (E2)	AOH (S1)	AOH (S2)	BOH1	NOH 1
Rig Tests																					
No. of tests completed	30	28	...	18	18	12	29	30	25	24	24	...	29	26	28	30	...	23	...	...	30
1st failure, rev × 10^6	1·5	1·8	...	0·08	0·41	1·7	1·4	2·2	1·3	7·1	0·5	...	1·3	3·9	1·1	2·1	...	5·0	...	...	1·4
L_{10} ,,	2·5	4·0	...	0·4	1·2	3·0	4·6	3·1	2·8	7·6	2·5	...	4·1	4·6	1·6	3·2	...	6·2	...	...	2·6
L_{20} ,,	4·4	8·0	...	0·9	1·5	5·1	7·2	5·4	9·4	9·3	5·7	...	7·3	7·1	3·5	5·5	...	8·0	...	...	4·0
L_{50} ,,	12·1	20·6	...	1·6	2·1	6·5	12·0	12·2	13·3	21·5	17·8	...	15·6	42·5	16·0	12·4	...	13·3	...	...	7·8
$L_{av.}$,,	16·8	23·5	...	3·8	5·9	7·4	14·5	18·1	21·4	26·2	22·5	...	22·7	36·3	23·1	20·3	...	19·2	...	...	11·8
Range 1st failure ,,	1·5– 1·8	...		0·08–1·7			1·3– 7·1			...	...	1·1– 3·9			2·1– 5·0			...	...		
,, L_{10} ,,	2·5– 4·0	...		0·4–3·0			2·8– 7·6			...	...	1·6– 4·6			3·2– 6·2			...	...		
,, L_{20} ,,	4·4– 8·0	...		0·9–5·1			5·4– 9·4			...	...	3·5– 7·3			5·5– 8·0			...	...		
,, L_{50} ,,	12·1–20·6	...		1·6–6·5			12·0–21·5			...	...	15·6–42·5			12·4–13·3			...	...		
,, $L_{av.}$,,	16·8–23·5	...		3·8–7·4			14·5–26·2			...	...	22·7–36·3			19·2–20·3			...	...		
Bearing Tests																					
No. of tests completed	...	23	26	...	...	...	24	23	28	30	...	...	...	...	...	...	...	...	...	...	...
1st failure, rev × 10^6	...	5·4	0·6	...	...	...	0·2	2·2	0·6	4·0	...	...	...	...	...	...	...	...	...	...	...
L_{10} ,,	...	7·0	1·0	...	...	...	1·2	9·5	1·6	10·4	...	...	...	...	...	...	...	...	...	...	...
L_{20} ,,	...	9·5	1·3	...	...	...	2·0	14·0	3·0	14·5	...	...	...	...	...	...	...	...	...	...	...
L_{50} ,,	...	17·5	2·0	...	...	...	5·8	43·0	5·3	23·9	...	...	...	...	...	...	...	...	...	...	...
$L_{av.}$,,	...	25·7	2·7	...	...	...	6·7	56·3	6·0	24·6	...	...	...	...	...	...	...	...	...	...	...
Wöhler Tests																					
Average hardness, DPN	800	849	...	...	...	...	800	815	795	795	...	820	797	778	...	842	788	787	800	813	806
Limiting fatigue stress, ±tons/in²	39·0	44·0	...	...	...	...	47·0	41·0	42·5	48·5	40·0	41·5	56·0	61·0	...	45·0	47·5	48·25	...	44·0	44·0
Δs $10^6 - 10^7$ cycles, ±tons/in²	9·7	9·7	...	...	...	...	6·6	10·2	7·1	14·7	4·8	11·9	1·6	3·2	...	16·8	2·5	7·1	3·2	8·2	10·6
Endurance (cycles × 10^6) at ±58 tons/in² ± tons/in²	0·24	0·30	...	...	...	...	0·34	0·40	<0·1	4·9	<0·1	0·84	1·45	37·0	...	1·13	<0·1	0·94	<0·1	0·19	1·05
Range limiting fatigue stress ± tons/in²	39·0–44·0	...		...	...	...	41·0–48·5			...	...	56·0–61·0			45·0–48·25			...	...		
Range Δs ($10^6 - 10^7$ cycles), ± tons/in²	9·7	...		...	...	...	6·6–14·7			...	...	1·6– 3·2			2·5–16·8			...	...		



4 *Load/life relationship*



5 *Relationship between total thrust load and* $\frac{1}{\sqrt{L_N}}$

thrust bearing. The three component parts of the test assembly are shown in Fig.3. The use of a thrust bearing rather than the radial type normally used in commercial rig tests would be expected to reduce the scatter between individual tests owing to the greater surface area exposed to the load. The cage of the standard bearing is operated with 9 balls in place of the normal 18 as another means by which the total load required for a given stress level could be reduced. Each side of the test specimen is used for a life test.

Preparation of test specimens

The specimens are rough-machined before heat treatment leaving a grinding allowance of 0·01 in. on the o.d. and 0·01 in. per face on the thickness. After heat treatment the faces of the specimen are lightly rubbed on emery paper to remove scale. The specimen is then fitted on a mandrel and the outside diameter ground on a cylindrical grinder to the finished dimensions. The actual test faces are ground using a magnetic chuck and taking special precautions to ensure that the faces are absolutely flat. The grinder spindle speed used is 60 rev/min. The wheel is lightly dressed when 0·003 in. of material remain to be removed. Using this method a finish of 5 μ in. is produced.

Test procedure

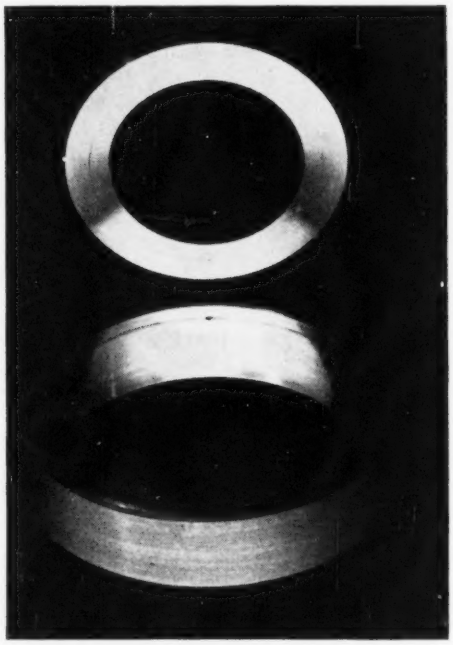
Before the test begins the housing containing the test bearing is filled with light machine oil, filtered before use to remove any abrasive particles. A drip feed maintains a constant flow of oil during the course of the test.

Following a preliminary test series carried out at varying loads in order to establish the relationship between load and life, the test conditions were standardized to give an average life of the order of 100–200 h as recommended by the bearing manufacturers. An operating speed of 1500 bearing rev/min is used and the total thrust load applied is 750 lb. Under these conditions, the values of maximum compressive stress and maximum shear stress calculated on the basis of the Hertzian theory are 563000 and 181600 lb/in^2 respectively. These figures will tend to be higher than those which apply in practice, however, as no account has been taken in the calculations of the plastic deformation which occurs at the points of contact.

The tests have been continued until failure occurs, or until 50×10^6 bearing revolutions have been completed, whichever occurs first. It was not considered necessary to continue the tests after the completion of 50×10^6 revolutions, which corresponds to a life of about 550 h, as in bearing tests the main interest lies in determining the low-life performance. It is most important that the apparatus should be able to detect any failure as soon as this occurs and for this purpose an automatic cut-out has been designed. The operation of this cut-out depends on the marked change in the noise output of the machine which accompanies the onset of failure. The vibration signal derived from two accelerometers mounted on diametrically opposite sides of the test bearing housing is made to operate a relay which controls the main power supply to the machine. An hour-meter is also included which enables an accurate record to be obtained of the duration of each test.

Rig test results

The preliminary series of tests carried out at different load levels to establish the order of life values associated with various loads, was also used to check whether the results agreed with the well known life

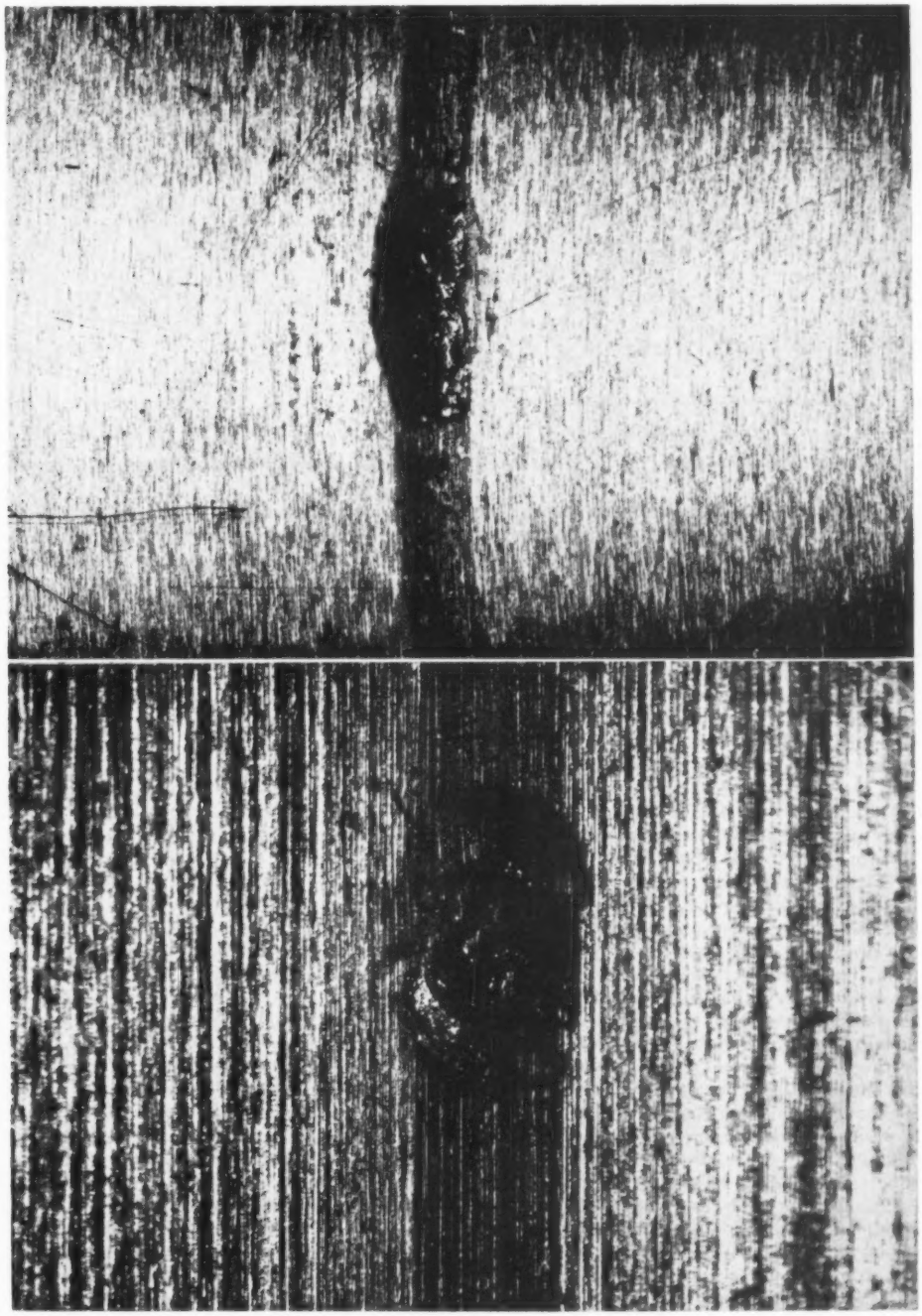


6a *Appearance of typical failures*

formula* for bearings. There was also considerable interest in the form of the failure obtained.

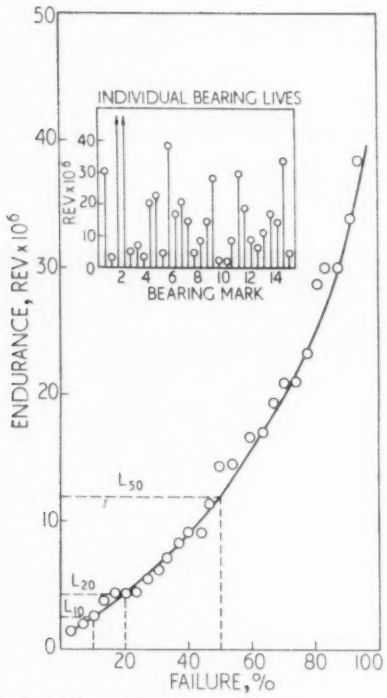
The results of these tests are given in Fig.4. It will be appreciated that only two, or at the most three, tests were carried out at each load and no attempt was made to establish a mean life at each load level. Figure 5 shows, however, that when the results are considered in terms of the life formula, a reasonable approximation to a linear relationship is obtained and it was concluded that this simulated form of bearing test is capable of giving life values which show a similar relationship to load as that given by conventional bearing tests. The failures obtained were also

* $L_N = (C)/(P)^3$ where C = specific capacity i.e., load-carrying capacity for life of 10^6 rev
P = bearing load
L_N = life under bearing load P, rev × 10^6

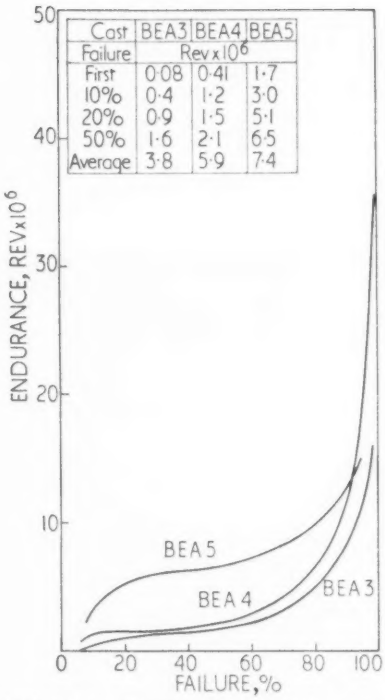


top experimental test bearing
bottom standard production race

6b *Typical failures*



7 *Typical life dispersion curve*


Cast | BEA3 | BEA4 | BEA5
Failure | Rev x 10⁶
First | 0·08 | 0·41 | 1·7
10% | 0·4 | 1·2 | 3·0
20% | 0·9 | 1·5 | 5·1
50% | 1·6 | 2·1 | 6·5
Average | 3·8 | 5·9 | 7·4
ENDURANCE, REV x 10⁶
FAILURE, %
BEA 5
BEA 4
BEA 3

8a *Basic electric arc. Experimental low-sulphur casts*

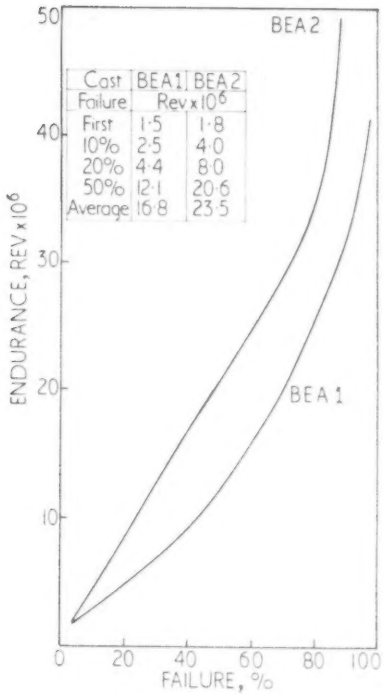
similar to those which occur in commercial tests and consisted of a small pit showing fatigue characteristics. A typical failure is shown in Fig.6*a* together with a failure in a standard production race. Figure 6*b* shows the same failures at a magnification of ×20. All subsequent tests were carried out under the standardized conditions of load (750 lb).

In bearing manufacturers' tests the degree of scatter between the life values of individual bearings, generally makes it necessary to do 30 tests to provide a statistical basis for the assessment of the properties. Guidance from bearing manufacturers was sought in order that the results of rig tests could be presented in a manner which would allow a direct comparison to be made with production test data. Consequently, the data given in this paper have been based on about 30 tests on each cast, except in the case of casts BEA3, 4, and 5, where, owing to the small quantity of material available for experimental purposes it was only possible to carry out 18, 18, and 12 tests respectively. The actual number of tests carried out on each cast is given in Table II. Life has been measured in terms of the number of revolutions of the bearing and all the results for a cast are presented in the form of life dispersion curves. A typical curve of this type with the actual life values obtained is shown in Fig.7. The curves have been used to derive the L_{10}, L_{20} and L_{50} values which reference to Fig 7 will show are the lives that will be reached or exceeded by a given proportion of all the bearings tested. It is values such as these from bearing tests that are normally used for bearing design purposes. Another very important property, particularly in bearings intended for high-duty applications, is the minimum life obtained on each cast and this has also been recorded together with the average life. In calculating the latter, it has been necessary to give a finite life to the bearings which have remained unfailed after completing 50×10^6 revolutions, and a life of 50×10^6 bearing revolutions has been arbitrarily chosen for this purpose.

The life curves obtained for the various casts tested are shown in Figs.8*a–e* and the results are summarized in Table II.

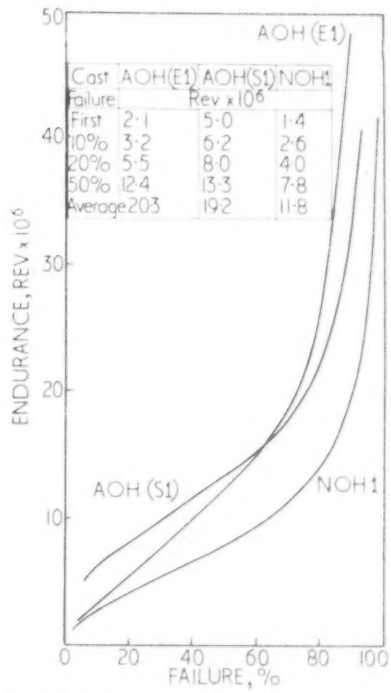
It will be seen that considerable differences in properties have been obtained not only between steels made by different steelmaking methods, but also between individual steels made by any one method. There are also differences in the manner in which the lives given by individual bearings are distributed, with the result that a good average performance is not necessarily associated with a good low-life performance. In comparing the order of merit of the various steels, a different grading is thus obtained depending on the method of assessment. From the point of view of bearing performance, however, the low-life properties are the most important criterion, and the elimination of low-life members is the prime object of the steelmaking trials at present being carried out.

Owing to the amount of scatter obtained, many more tests are required before any final conclusions can be drawn. The data so far obtained do however indicate that some general features may be associated with each steelmaking method. In assessing the results, it is convenient to use the data obtained on CaSi-deoxidized basic electric-arc quality steels as a basis of comparison. More tests have been completed on this quality than on casts made by any other steelmaking method, and consequently there is more confidence in the range of properties produced. The effect of different steelmaking methods on the form of the



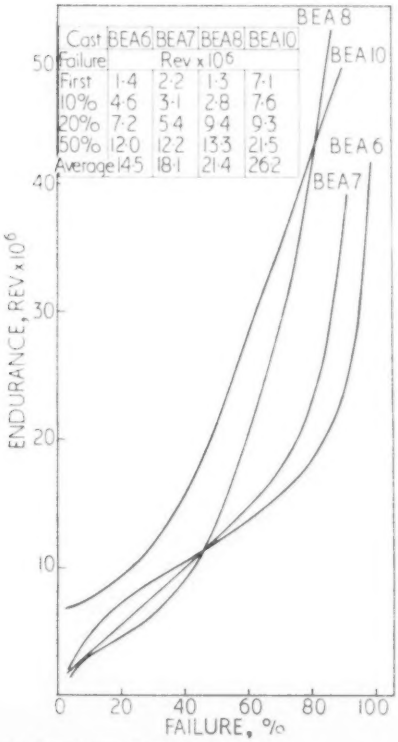
Cast	BEA1	BEA2
Failure	Rev x 10⁶	
First	1·5	1·8
10%	2·5	4·0
20%	4·4	8·0
50%	12·1	20·6
Average	16·8	23·5

8b *Basic electric arc. Standard practice*



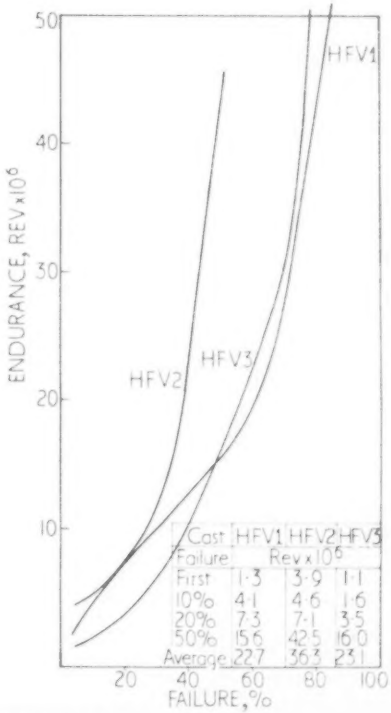
Cast	AOH(E1)	AOH(S1)	NOH1
Failure	Rev x 10⁶		
First	2·1	5·0	1·4
10%	3·2	6·2	2·6
20%	5·5	8·0	4·0
50%	12·4	13·3	7·8
Average	20·3	19·2	11·8

8d *Open-hearth casts*



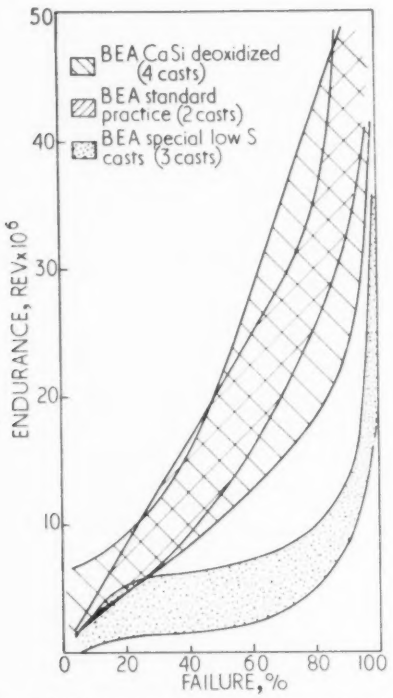
Cast	BEA6	BEA7	BEA8	BEA10
Failure	Rev x 10⁶			
First	1·4	2·2	1·3	7·1
10%	4·6	3·1	2·8	7·6
20%	7·2	5·4	9·4	9·3
50%	12·0	12·2	13·3	21·5
Average	14·5	18·1	21·4	26·2

8c *Basic electric arc.* CaSi-*deoxidized*

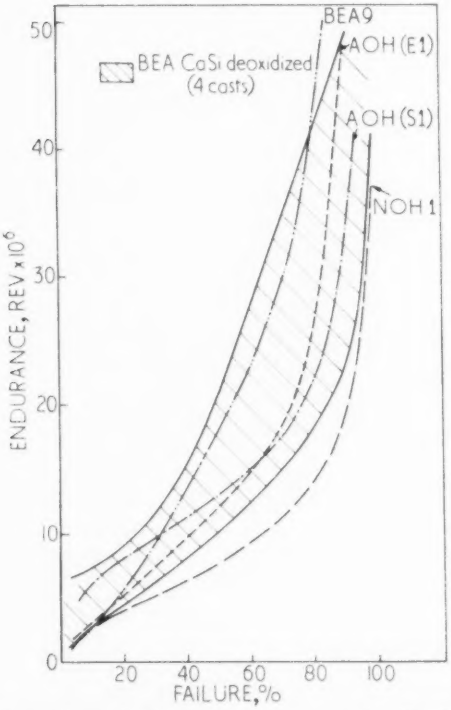


Cast	HFV1	HFV2	HFV3
Failure	Rev x 10⁶		
First	1·3	3·9	1·1
10%	4·1	4·6	1·6
20%	7·3	7·1	3·5
50%	15·6	42·5	16·0
Average	22·7	36·3	23·1

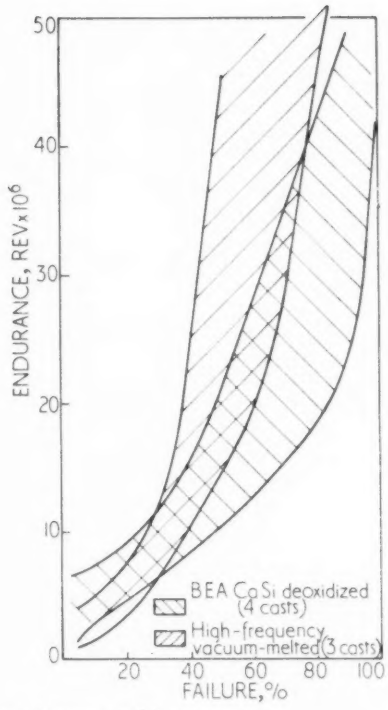
8e *High-frequency vacuum-melted casts*



9a *Effect of* CaSi-*deoxidation and low* S *content in basic electric arc steels*



9b *Comparison of BEA* (CaSi- *and gaseous deoxidized*) *with open-hearth quality steels*

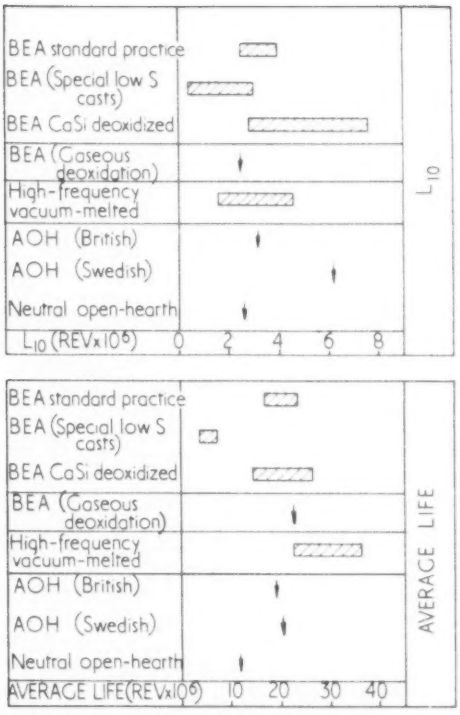


9c *Effect of vacuum melting*

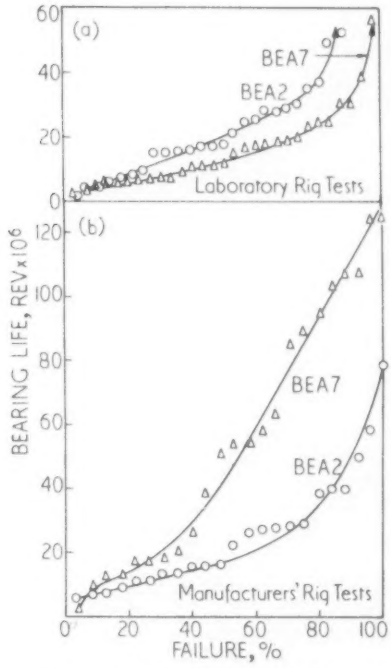
life curve in relation to the scatter band for CaSi-deoxidized basic electric arc steels is shown in Figs. 9*a–c*. As already stated the main interest is in the L_{10} and L_{av} values, and the range of these values given by each steelmaking method is summarized in Table II and also shown diagrammatically in Fig.10.

It will be seen that the best low-life performance is given by Swedish acid OH and CaSi-deoxidized basic electric arc casts. All the other qualities show lower L_{10} values and, with the exception of the special low-sulphur basic electric arc casts which are much inferior, give very similar performances. When the average life is considered, however, the Swedish acid OH and CaSi-deoxidized basic electric arc casts show no advantage compared with other air-melted qualities; in fact, all the air-melted qualities, with the exception of the 'neutral OH' cast and the low-sulphur basic electric arc casts, produce a very similar result. The neutral OH cast is slightly inferior and the special low-sulphur basic electric arc casts are very much inferior to other air-melted qualities, whilst the vacuum-melted casts give the best performance of all the steels tested.

The performance of the vacuum-melted casts provides one of the most interesting features of the results obtained. These steels show considerably greater spread between the lives of individual bearings than do air-melted quality steels. As an example of the amount of scatter obtained, in cast HFV2, over 40% of the 26 bearings tested gave a life of greater than 50×10^6 bearing revolutions, whereas 33% of the bearings failed at a life of less than 10×10^6 revolutions. The important feature is that, although the average life is high, the low-life performance is comparatively poor. Figure 9c shows that the low-life performance



10 *Effect of steelmaking variables on L_{av} and L_{10}*

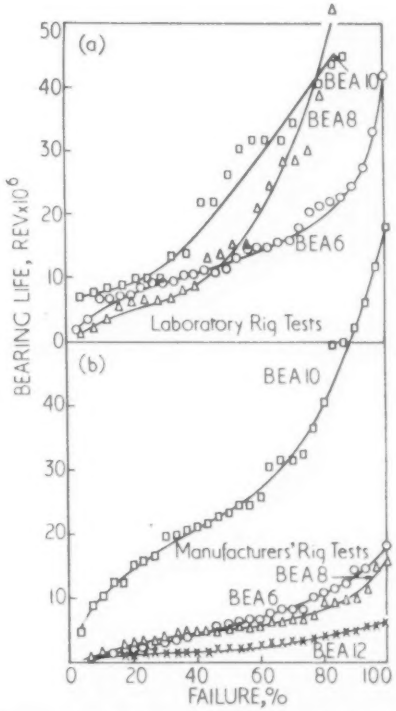


11a *Comparison of laboratory and manufacturers' rig test results*

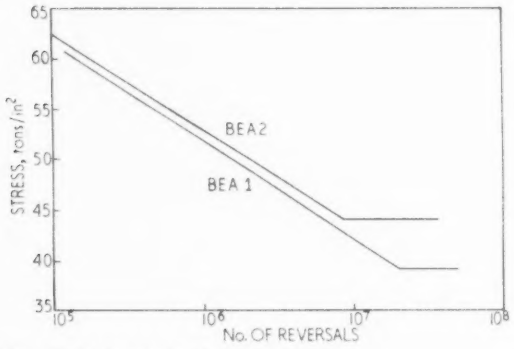
may be inferior to both basic electric arc, CaSi-deoxidized quality, and also Swedish acid OH quality. There is some indication, however, on the basis of tests at present being carried out, that the same relationship may not be true under lower stress conditions.

Another interesting feature of the results concerns the effect of CaSi-deoxidation which the bearing industry thinks improves service performance of bearings. This treatment shows no effect on average life, but produces a significant improvement in low-life performance, as depicted in Fig.9*a*. It is particularly encouraging that the same features are shown by the rig test and in service performance.

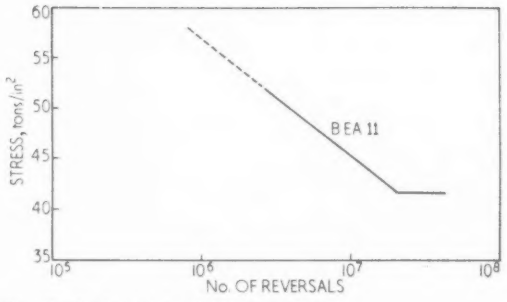
With regard to the other air-melted qualities, it will be seen from Fig.9*b* that the life curves obtained for both English and Swedish acid OH qualities lie within the scatter band given by the basic electric arc CaSi-deoxidized casts. The average lives of these two steels are very similar, but the Swedish steel shows the better low-life performance and has an L_{10} value which approaches that of the best basic electric arc material. The neutral OH cast is disappointing, the results being poor both as regards average life and low-life performance. In comparing the properties of OH and basic electric arc steels it must be remembered that only single casts of each of these types have been tested, so that the life curves obtained could represent the bottom of the scatter bands for each steel. If this is the case the differences that have been suggested between their properties and basic electric arc material may be somewhat exaggerated. The results obtained on the first experimental cast on which it was sought to improve the quality by modifying the deoxidation practice are shown in Fig.9*b*. Although the average



11b *Comparison of laboratory and manufacturers' rig test results*



12a *Basic electric arc. Standard practice*



12c *Basic electric arc. High manganese*

life has been increased by this modification there has been little effect on low-life performance. The result is regarded as being encouraging and it is hoped that the more successful application of this technique which has since been achieved will lead to an all-round improvement.

Bearing manufacturers' tests

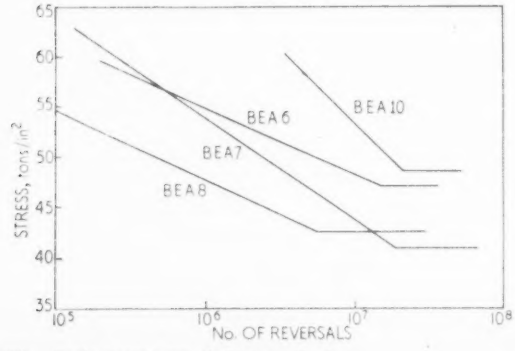
Through the co-operation of two bearing manufacturers, actual bearing tests have been completed on five of the basic electric arc casts on which laboratory rig tests are available (BEA2, BEA6, BEA7, BEA8 and BEA10). In addition, bearing tests only are available on a cast BEA12 in which the steelmaking procedure was to the standard pattern. The results of bearing tests are given in Table II. Since each bearing manufacturer tests under his own conditions, no attempt has been made to draw comparisons between the results of the two casts tested at one works with the four tested at the other. Further, because their rigs are loaded radially, and the laboratory rig operates under thrust load, from the onset it was not expected that the level of life values would be directly comparable. The real interest was in whether the laboratory rig tests graded the steels in a similar manner to the bearing tests and could, therefore, be accepted without question for routine assessment of steel quality. The comparison is given in Figs. 11*a* and *b* where the hoped for correlation is shown only in the case of one cast BEA10 which both methods graded as the best steel tested. The other casts are not given the same order of merit by both tests, the bearing test being consistent in attributing superior properties to the casts deoxidized with calcium silicide.

Although the evidence supports the view that the merit rating of steel is influenced by the level of stress applied in the test, these results might have discouraged further work had it not been for a report received privately from one of the bearing manufacturers who had been running tests in a similar laboratory rig on the end faces of bearing rings that had already been tested as bearings. Under these circumstances they claim to have obtained a good correlation between the two types of test. A possible inference is that life measured in this manner is particularly sensitive to any heterogeneity in the steel and that the lack of correlation in the present work is the outcome of the random sampling for each test. In the case of cast BEA 10 both sets of samples were, as far as can be ascertained, from the same bar, while metallographic work on the samples used for each type of test in the cases of casts BEA2 and BEA7 confirmed the presence of some heterogeneity.

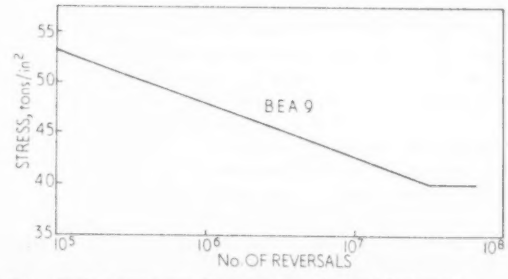
To explore this theory a further series of tests has been started with the bearing manufacturers. In one case two ingots have been poured uphill on the same plate, and one used for the production of the laboratory rig samples and the other for the production of the tubes for the bearing tests. Here it is also intended to test in the laboratory rig samples cut from the tubes used to make the bearings. In the other case the laboratory rig will be adapted to test the end face of bearings whose life curve has already been assessed.

Rotary bending tests

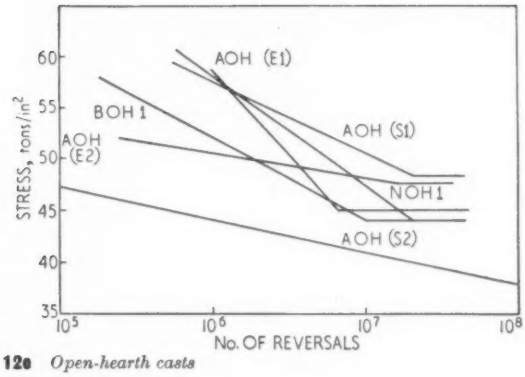
Standard fatigue tests were carried out under rotary uniform bending moment conditions, using ground and polished 0·300-in. dia. specimens. The material used was in the same heat-treated condition as that employed for rig tests and the average hardness value



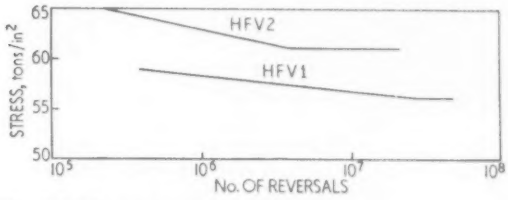
12b *Basic electric arc.* CaSi-*deoxidized*



12d *Basic electric arc. Gaseous deoxidation (first trial)*



12e *Open-hearth casts*



12f *High-frequency vacuum-melted casts*

obtained on the specimens after heat-treatment was 800 DPN. A minimum number of eighteen tests was carried out on each cast to establish with reasonable accuracy the limiting fatigue stress and also the form of the S–N curve at higher stresses. Six basic electric arc casts, three high-frequency vacuum-melted casts, four acid OH casts, one basic OH and one neutral OH cast were tested as shown in Table I. In the cases of casts AOH(E1) and AOH(S2), however, the scatter in results was such that the S–N curves obtained can only be regarded as approximate. Tests were not continued beyond 20×10^6 cycles as the main interest lay in the higher stress portion of the curve. The S–N curves are shown in Figs.12*a–f* and a summary of the results is given in Table II.

There is a generally held opinion, both in the UK and the USA, that no correlation exists between conventional rotating beam fatigue test data and bearing performance. Recent US work[8] however, has suggested that there may be a broad relationship between median life (50% failures) determined in bearing tests, and the limiting fatigue stress determined under rotary bending conditions.

The possibility of such a correlation might be argued from the data of this investigation, but what does seem clear is that it cannot be applied generally owing to the apparent dependence upon the loading conditions used in the bearing test. Comparison of the average rig life with the corresponding LFS values (Table II) show quite definitely that under these conditions there is no general correlation.

In rotary bending tests the various steels differ in limiting fatigue stress values and show interesting differences in the slopes of the S–N curves at higher stress levels.

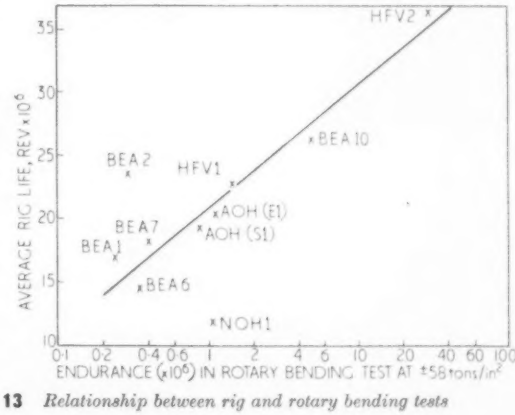
Considering first the limiting fatigue stress values, it will be seen that the steels fall into two distinct groups, namely air-melted steels which range from 39–48·5 tons/in² and vacuum-melted steels with a much higher range of 56–61 tons/in². In the air-melted steels the steelmaking procedure showed no marked effect upon the level of the values obtained. The full range is represented by the standard and CaSi-deoxidized basic electric arc steels, no benefit being noted from the CaSi addition. The higher manganese steel and also the special cast with modified deoxidation give limiting fatigue stress values within the same scatter band. The OH steels on the other hand, show considerably less scatter in limiting fatigue stress values although the fewer number of casts tested is likely to be a contributory factor. This band extends from 44·0 to 48·25 tons/in² which lies at the top of the basic electric arc band.

The differences of slopes in the higher stress sections of the various S–N curves is represented quantitatively in Table II by the decrease in stress required to increase the endurance from 10^6 to 10^7 cycles. The slopes appear to be independent of the limiting fatigue stress values and the differences are most marked between the air-melted qualities and the vacuum-melted steels, the feature of the latter being their flatness. Thus a steel which gives a relatively high limiting fatigue stress may have a lower endurance life at higher stresses than a steel giving a much lower limiting fatigue stress value. This is well illustrated by the vacuum-melted cast HFV1 whose performance at stresses in excess of about 60 tons/in² is inferior to most of the air-melted qualities.

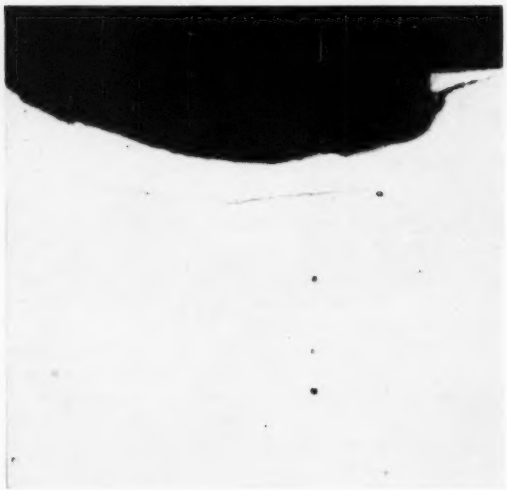
When the endurance values for the different steels are studied in conjunction with the average performance under bearing rig conditions it appears that with one or two exceptions the steels are placed in the same order of merit by both tests when the rotary bending fatigue stress is ±58 tons/in². Table II gives the endurance values at this stress: in Fig.13 these are plotted against the corresponding values of average rig life. Such a relationship is represented by the equation:

$$\text{Average rig life} \times 10^6 \text{ at 750-lb load} = 10{\cdot}9 + 10 \log_{10} (\text{Endurance life} \times 10^5 \text{ at 58 tons/in}^2.)$$

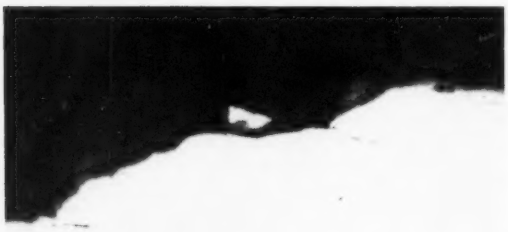
The results on casts BEA8 and BEA9 which do not fit this relationship are omitted from Fig.13: it is noteworthy that some deviation exists in the cases of casts BEA2 and NOH1. Only two of these four casts, BEA8 and BEA2, have been tested as actual bearings and they were among those whose results failed to



13 *Relationship between rig and rotary bending tests*



14a *Typical failures in rig specimens showing sub-surface cracks* ×200



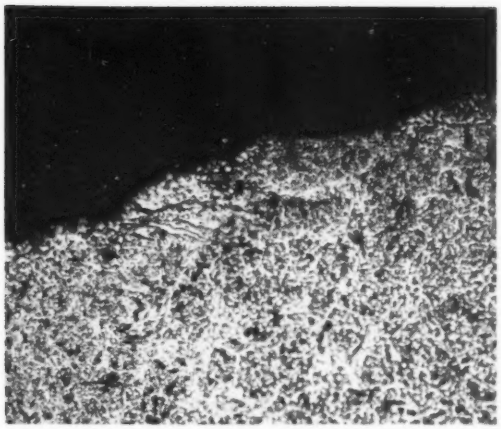
14b *Typical failures in rig specimens showing edge cracks* ×750

14c *Typical failures in rig specimens showing extensive cracking below surface* ×200

support the existence of a reliable relationship between the bearing test and the laboratory rig test. Consequently the possibility that steel heterogeneity might be colouring the results is also being investigated in this case through metallographic examinations of the rotary bending specimens at the origin of failure.

The correlation that has been suggested is obviously peculiar to the particular rig test conditions applying in this investigation. It is interesting to speculate, however, on the outcome of a similar relationship under other conditions of test. If the assumption is valid that whatever the level of stress in the bearing test there is a corresponding rotary bending stress at which the average endurance will be related to the average bearing life, then this life can be estimated from the results of rotary bending tests at this stress. The time of testing could, thereby, be reduced con-

14d *Typical failures in rig specimens showing sulphide inclusions close to failure* ×750



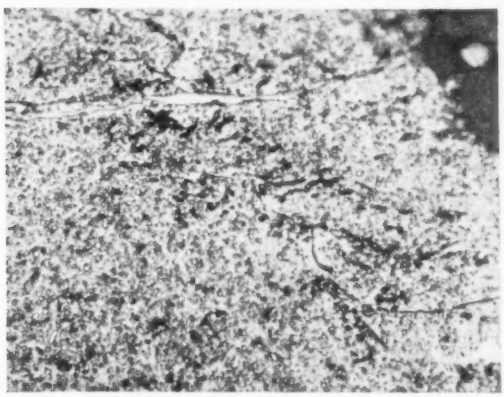
14e *'White areas' associated with cracks* ×750

siderably, and if at the same time the results of thirty rotary bending tests at the specific stress produced a life distribution curve corresponding to the bearing tests, then an estimate could be made of low-life performance. However, even if ultimately this is all shown to be true, it will be necessary to establish that, as the result of the difference in the form of the tests, there is no difference in the degree of scatter between one test and the other.

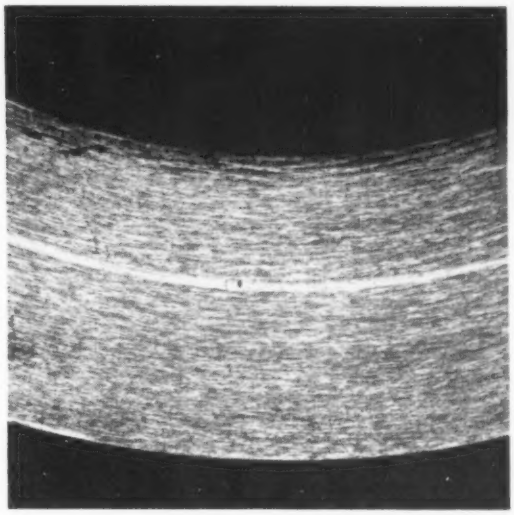
To establish the validity of such a relationship is a long-term project, particularly as it involves carrying out bearing rig tests at lower stresses than are produced by the 750-lb load normally used. So far only a few preliminary tests at a load of 500 lb have been completed on casts BEA6 and HFV1, and although it is obviously too early to draw any definite conclusion, the indications are that the relative performance of the vacuum-melted steel is considerably improved, in agreement with what would be expected from the rotary bending performance. The establishment of this concept would render questionable the value of the commonly used overload bearing tests as a measure of service performance.

Examination of failures

A detailed examination was carried out on a number



14f *'White areas' associated with cracks* ×750



14g *Appearance of 'early' failure* ×4

of failures: Fig.14 shows the main features observed. Figure 14*a* shows a section taken at right angles to the track through the centre of a typical failure. The actual depth of the failure is about 0·003 in. and cracks were observed to a depth of 0·004 in. below the surface of the original specimen. Surface cracks are often seen at the edges of the main failure, as shown in Fig.14*b*. It seems that the development of failure leads to extensive cracking below the surface of the initial failure, and this is illustrated in Fig.14*c*. In only one case was a large inclusion found in the neighbourhood of the failure, which in this case happened to be a sulphide situated as shown in Fig.14*d* towards the edge of the failure. (Inclusions located near to the failure could become detached and lost in the debris.)

In the etched condition two of the specimens examined showed 'white' areas below the surface which

14h *Appearance of 'early' failure* ×100

appeared to be associated with sub-surface cracking. It is thought that these are martensite areas which have been produced by an intensive heating effect due to dislocation movement in the vicinity of the cracks. A typical white area is shown in Fig.14*e* and this appears at the edge of a failure in a position similar to that illustrated in Fig.14*b*. Similar areas were also found to be associated with the failure shown in Fig.14*c* and one of these is shown in Fig.14*f*.

In a further effort to obtain evidence of the origin and cause of breakdown a failure was examined in the very early stages of development. It will be appreciated how difficult it is to pick up a failure at this stage as normally it does not become apparent until the actual pit has been produced, and by that time, if there were any associated inclusions, they would probably have been lost. However, by means of extremely careful examination of a number of tracks which showed initial evidence of damage, the required failure was found. The appearance of this failure is shown (Fig.14*g*) at a magnification of ×4 and (Fig.14*h*) at a magnification of ×100. The direction of move-

14i *Progress of cracking through track* ×100

14j *Progress of cracking through track* ×100

14k *Progress of cracking through track* ×100

14l *Progress of cracking through track* ×100

14m *Progress of cracking through track* ×100

14n *Progress of cracking through track* ×100

ment of the balls is from left to right on the section of track shown and it is evident that a certain amount of battering has taken place to the right of the right-hand crack. The damage surrounding this crack suggests that it was formed first and that the crack to the left, where there is little or no evidence of damage in the surrounding material, was formed later, probably just before the test was discontinued.

The specimen was sectioned in a direction parallel to the track, and by extremely careful removal of successive layers of material by polishing it was possible to examine the failure from one side of the track to the other. Figures 14*i* to *n* show the appearance of the failure at each stage. It will be seen (Fig.14*i*) that at the front edge of the track the failure consists of a comparatively deep crack running almost vertically to the surface and extending to a depth of about 0·006 in., and at the opposite end of the ultimate failure, a shorter sub-surface crack running at an angle to the surface. As the centre of the track is approached the inclined crack gradually extends towards the second crack (Fig.14*j*) and ultimately to the surface (Fig.14*k*). The appearance of the failure at the centre of the track is shown in Fig.14*m* where the two main cracks have joined to form a continuous crack resulting in the separation of a portion of the material at this position. Still further through the track the cracking is less severe (Fig.14*n*), and eventually would be expected to be of a similar nature to that shown in Fig.14*i*.

The examination of this failure provides no definite indication of the position where the failure was initiated. From the general nature of the cracks observed, however, and the changes in the form of the cracking from one side of the track to the other, it is possible to suggest that the crack that is inclined to the surface was the first to form and that its start was below the surface. With the passage of the balls the portion of material immediately over this crack has been depressed (as evidenced by the battering of the track which occurs, Fig.14*h*) and adjacent material subjected to considerable stress. This eventually leads to complete failure with a portion of material being removed.

The examination to find inclusions which may have been associated with the failure was very thorough. The appearance at a magnification of ×500 of the two main cracks observed in the section taken through the edge of the track (Fig.14*j*), is shown in Figs.14*o* and *p*. There are a small number of inclusions present in the material immediately surrounding the crack that is inclined to the surface but none of these appear to have contributed in any way to the failure. The etched structure of the material surrounding the crack occurring below the approximate centre of the track is shown in Figs.14*q* and *r*, and once again, no structural feature can be observed which is obviously associated with the failure.

Metallurgical examination

A comprehensive metallurgical examination was carried out in an attempt to explain the differences in performance between the various steels and also to establish the reason for scatter between individual test results on any single steel. There have been two stages to this work which up to the present, has concentrated on the laboratory rig test specimens. In the initial work a selected number of failures was examined to assess the influence of residual elements, gas content, surface condition, hardness, nature of the track formed, metallurgical structure, and in a preliminary way, inclusions. In the second stage further

14o *Progress of cracking through track* ×500

work was carried out on inclusions which involved detailed counts on the material immediately adjacent to the failures.

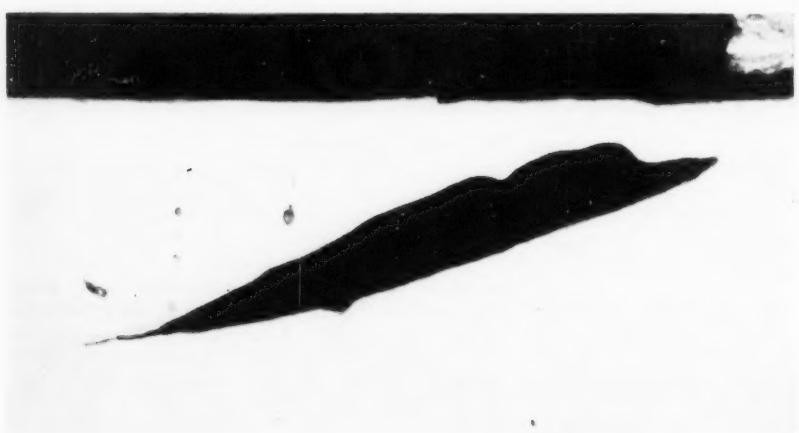
The results of the first series of tests are given in Tables III and IV and the main features of these results are summarized below.

Chemical analysis It has already been seen with regard to the main elements that all the steels examined had very similar analyses, with the exception of the special low-sulphur casts BEA3, BEA4 and BEA5, and the vacuum-melted casts, all of which had low sulphur and phosphorus contents. Table III shows that there were no significant differences in trace elements or gas content except in the case of the vacuum-melted cast which, as expected, had a low gas content. The results give no indication that the variation in performance can be explained in terms of chemical analysis.

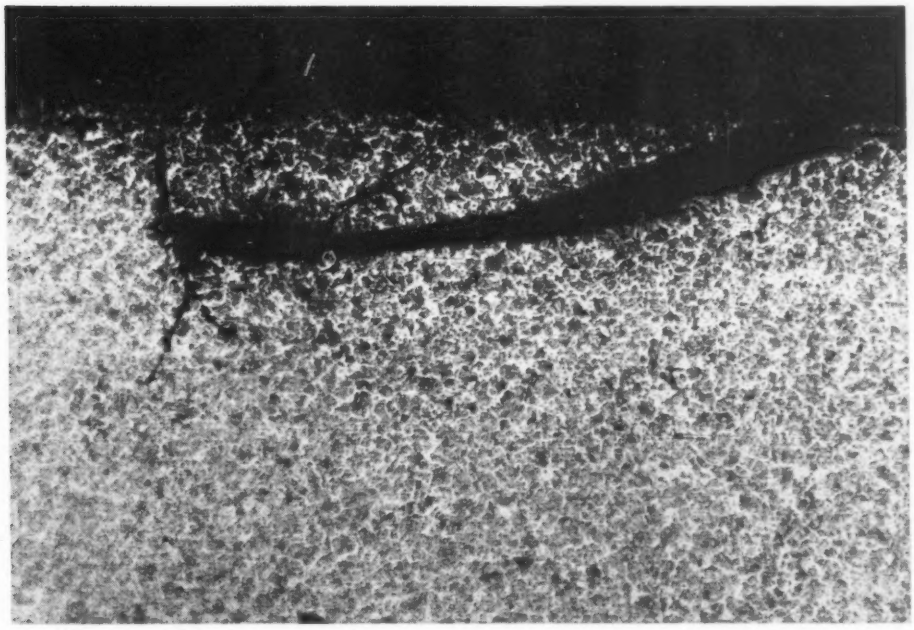
Surface condition (laboratory rig tests) The quality of the surface finish of a number of specimens was measured using Talysurf equipment, and in some cases autographic records of the track that formed during the test were obtained, from which it was possible to measure the approximate depth and width of the track. The surface finish is defined in terms of centre-line average (CLA) and on this basis the surface finish is similar for all the specimens examined with the exception of casts HFV1 and BEA6, which showed a somewhat better finish. This improvement coincided with a change in the method of grinding the specimens and this improved method has since been adopted as standard practice. It is not possible to assess the effect of surface finish on test performance, but it seems that so far as individual specimens within any one series are concerned, the scatter in result cannot be related to any variation in surface finish.

Track measurements The track measurements are interesting in that, in general, the width (which can be determined considerably more accurately than the depth) is similar for each of the specimens tested, and agrees extremely well with the value of 17×10^{-3} in., which is the width calculated from consideration of the loading conditions and contact area. The fact that all the tracks formed are of similar dimensions shows that, on application of the load, plastic deformation occurs very rapidly, with the balls forming their own track until the effective load is reduced to the point where no further plastic deformation takes place. It has been demonstrated elsewhere[9] that all the plastic deformation generally takes place during the first 100 revolutions of the test, after which a state of equilibrium is attained.

Hardness The general hardness level of the various steels varies between 700 and 800 DPN, but there is



14p *Progress of cracking through track* ×500

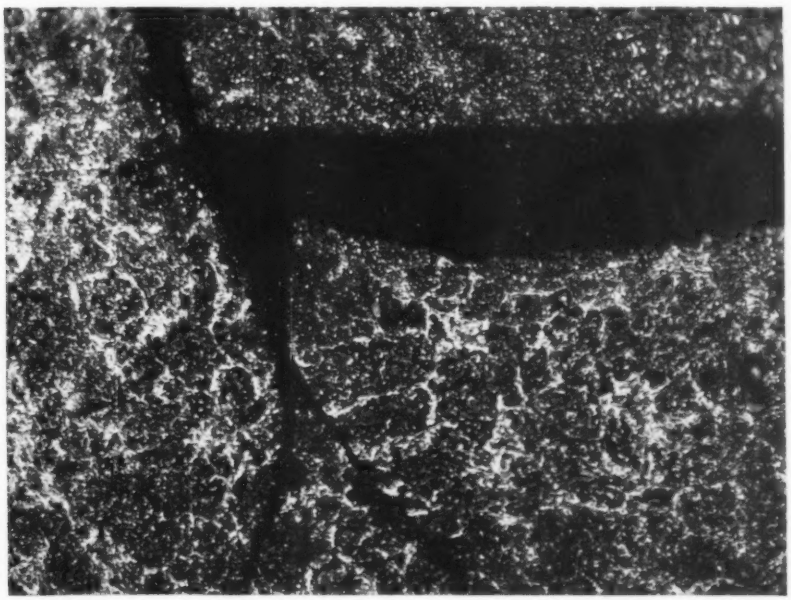


14q *Progress of cracking through track* ×200

no apparent relationship between the hardness and the average life obtained for each cast. The individual specimens examined from each cast all show very similar hardness values and the difference in life given by one specimen and another cannot, therefore, be explained in terms of a hardness difference. The track hardness values reported are very approximate owing to difficulty in testing at this position but the results indicate that the increase in hardness due to rolling action is very similar in each case and of the order of 20–30 hardness points.

Metallographic examination The general structure of all the steels was very similar and consisted of spheroidized carbide in a lightly tempered martensite matrix. There was little evidence of carbide segregation and no correlation between this and the life values obtained. Typical structures are shown in Figs.15*a* and *b*.

Assessment of inclusion content Initially a standard count at a magnification of ×100 was carried out on a number of the steels but this failed to give any correlation with life. It was, therefore, decided to carry out a detailed survey taking into account sizes and types of inclusion. This was done by examining



14r *Progress of cracking through track* ×750

TABLE III Effect of chemical analysis and physical condition of specimen on life

Steel quality	Cast	$L_{av.}$ for cast	Bearing identity mark	Bearing life, rev $\times 10^6$	Chemical analysis, % Ti	Cu	Sn	V	Co	Al	O	N	Av. specimen hardness, DPN	Surface finish CLA	Track measurements Depth, in. $\times 10^{-6}$	Width, in. $\times 10^{-3}$	Hardness av., DPN
Basic electric arc, standard practice	BEA1	16·8	AT	51·7	<0·01	0·10	<0·02	<0·02	<0·02	<0·01	0·0020	0·0067	802				830
			AB	43·0									806				816
			BT	2·0									794				830
			BB	1·5									786				816
Basic electric arc, special low-S casts	BEA3	3·8	AT	0·8	...	...	...	...	...	...	0·0018	0·0076	722	7			740
			AB	0·1									722	10			722
			BT	2·2										8	No obvious track		
			BB	0·8										6	No obvious track		
			CT	10·4	<0·01	...	<0·02	<0·02	<0·02	<0·01	0·0023	0·0068	729	7			
			CB	16·4									725	9½			
			DT	6·9										12	57	15·0	728
			DB	0·7										15½	46	19·1	746
	BEA4	5·9	AT	1·7	...	...	...	...	...	...	0·0022	0·0057	735	8½			720
			AB	0·4									734	13¾			724
			BT	1·4										14	No obvious track		
			BB	1·4										14½	27	13·5	
			CT	36·3	...	...	...	...	...	...	0·0021	0·0064	718	13			735
			CB	19·8									725	9			737
			DT	3·3										12	49	15·8	
			DB	3·3										14½	42	17·9	
			ET	6·6	...	...	...	...	...	...	0·0025	0·0066	739	15½			724
			EB	10·1									737	13			755
	BEA5	7·4	AT	6·8										10¼	26	15·9	
			AB	5·2										12¾	61	18·0	
			BT	7·0	<0·01	<0·02	<0·02	<0·02	<0·02	0·011	0·0023	0·0048	727	14¼			733
			BB	13·5									730	10			798
			CT	6·5	<0·01	<0·02	<0·02	<0·02	<0·02	0·011	0·0021	0·0054	730	10½			724
			CB	6·6									739	11			728
Basic electric arc, CaSi – deoxidized	BEA6	14·5	AT	41·9	<0·01	0·10	0·04	<0·02	<0·02	<0·01	0·0033	0·0078	761	4¾	24	12·7	803
			AB	15·4									756	3½	20	17·0	777
			BT	9·7										7	27 (27)	17·4 (28·3)	
			BB	10·2										3	19	15·2	
			CT	6·4									771				833
			CB	9·7									784				808
	BEA10	26·2	AT	9·8	<0·01	...	<0·02	<0·02	<0·02	<0·02	0·0016	0·0079	753	9			771
			AB	88·6									748	8¾			755
			BT	13·1										7½			
			BB	13·9										3¾	17	15	
			CT	34·2	...	...	...	...	...	...	0·0018	0·0060	752	8½			747
			CB	30·2									743	14			759
			DT	62·5										12¼	75	20·0	
			DB	7·1										12	63	10·2	
			ET	78·4NF	...	...	...	...	...	...	0·0015	0·0096	743	8½			748
			EB	21·6									742	8¾			761
High-frequency vacuum-melted	HFV1	22·7	AT	2·4	<0·01	<0·02	<0·02	<0·02	<0·02	0·028	0·0011	0·0013	745	12¼			752
			AB	5·3									748	15¾			778
			BT	14·8	<0·01	<0·02	<0·02	<0·02	<0·02	0·030	Nil	0·0012	730	7½			
			BB	52·2									730	6½			760
			CT	10·0										6½	53	18·3	
			CB	1·3										9	29	15·0	
			DT	19·9	<0·01	<0·02	<0·02	<0·02	<0·02	0·027	0·0001	0·0008	744	5½			744
			DB	27·3									746	3¾			744
			ET	...													
			EB	34·8										9¾	79	20·7	

NF indicates specimen did not fail

TABLE III (continued) Effect of chemical analysis and physical condition of specimen on life

Steel quality	Cast	Lav. for cast	Bearing identity mark	Bearing life, rev $\times 10^6$	Chemical analysis, % Ti	Cu	Sn	V	Co	Al	O	N	Av. specimen hardness, DPN	Surface finish CLA	Track measurements Depth, in. $\times 10^{-6}$	Width, in. $\times 10^{-3}$	Hardness, av. DPN
English acid open-hearth	AOH (E1)	20·3	AT	17·2	<0·02	0·10	<0·02	<0·02	<0·02	<0·01	0·0021	0·0043	749				757
			AB	40·8									740				762
			BT	10·7									742				876
			BB	4·3									741				777
Swedish acid open-hearth	AOH (S1)	19·2	AT	15·4	<0·01	<0·02	<0·02	<0·02	<0·02	0·0130	0·0017	0·0042	707	14			723
			AB	15·7									707	13			726
			BT	19·7										14	19	10·7	
			BBB	25·3										123	31	15·9	
			CT	5·9	<0·01	<0·02	<0·02	<0·02	<0·02	0·0130	0·0019	0·0042	697	12			704
			CB	11·4									708	141			828
			DT	12·9										22	240	26·6	
			DB	5·0										123	32 (30)	12·4 (15·3)	
			ET	40·3	<0·01	<0·02	<0·02	<0·02	<0·02	0·0130	0·0019	0·0035	695	134			713
			EB	...													

NF indicates specimen did not fail

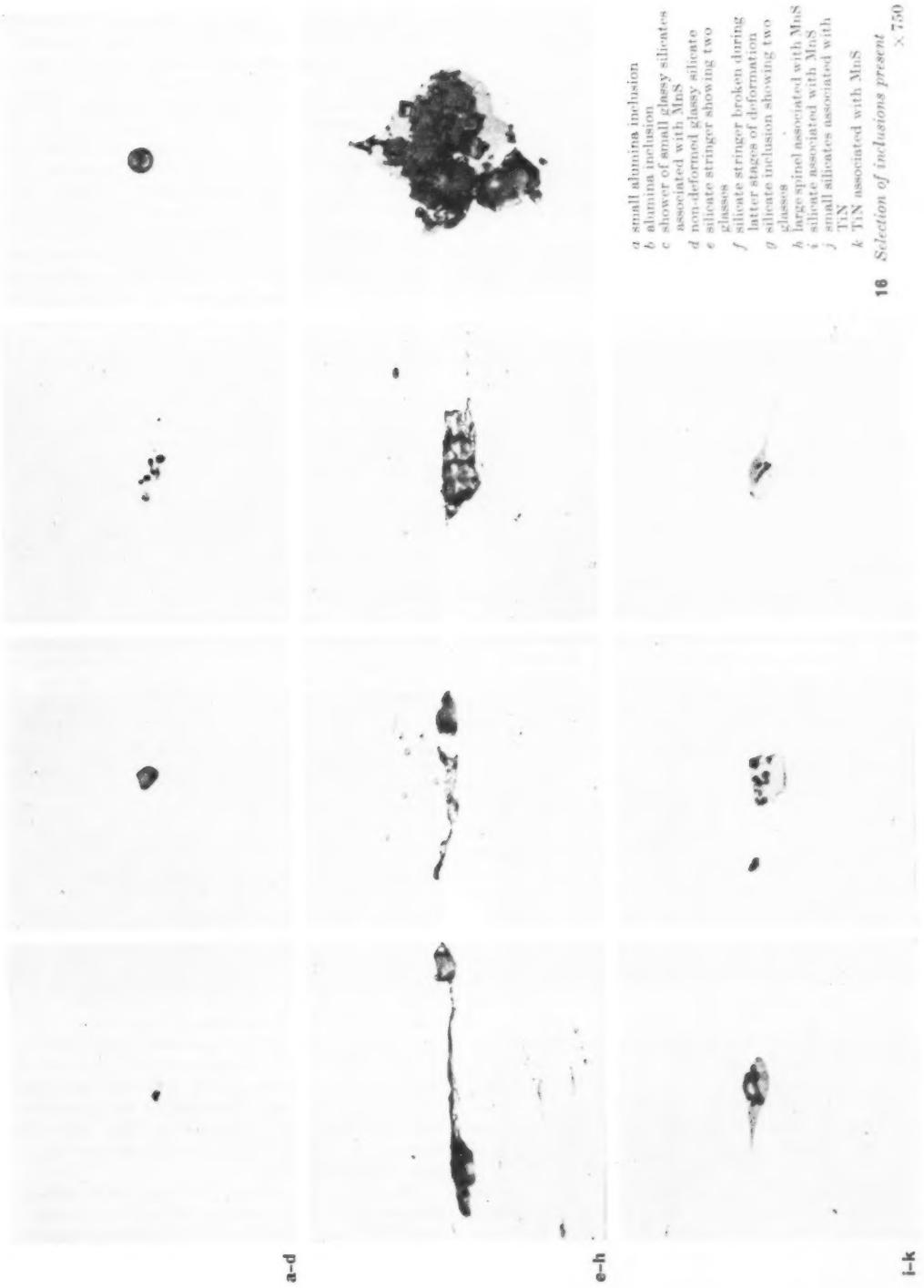
15 *Typical structure* ×750

172 randomly selected fields at a magnification of ×750, representing a total specimen area of just greater than 3 mm². Sulphide, alumina, silicate, and inclusions of the titanium nitride group were identified, and each type was classified into five size ranges depending on the width at ×750. The ranges selected were 0–1½ mm (Class O); 1½–3 mm (Class 1); 3–6 mm (Class 2); 6–9 mm (Class 3); and greater than 9 mm (Class 4). Figure 16 shows the appearance of typical inclusions at this magnification.

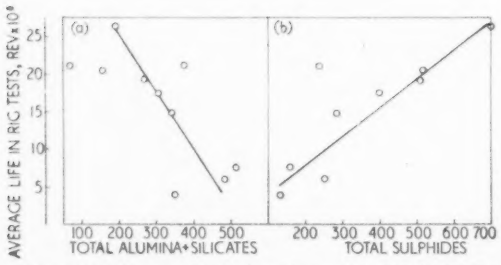
In an attempt to obtain a representative count on each steel three separate counts were made on each material, the specimens being re-polished between each run. Runs 1 and 2 were carried out by observer *A* and run 3 by observer *B*. In some cases, particularly in the identification of the alumina inclusions, there was a wide divergence between the results obtained by the two observers and also, in fact, between the two runs made by observer *A*. This, however, is to be expected in view of the extremely small inclusions that have been identified. In considering the relationship between inclusion count and rig test data the total of the three runs has been used and this represents the total number of inclusions of each type and size contained in a specimen area of just greater than 9 mm².

TABLE IV Inclusion counts, initial series

Steel quality	Cast	Av. rig life, rev $\times 10^6$	Standard inclusion count	No. of runs	Number of inclusions present per run of 172 fields: Sulphide 0	Sulphide 1	Sulphide 2	Sulphide 3	Sulphide 4	Alumina 0	Alumina 1	Alumina 2	Alumina 3	Alumina 4	Silicate 0	Silicate 1	Silicate 2	TiN 0	TiN 1	TiN 2	Total alumina + silicates	Total sulphides
Basic electric arc, standard practice	BEA1	16·8	...	1	38	24	2	2	0	94	27	6	0	0	0	0	0					
				2	150	18	3	7	0	89	23	1	1	0	1	1	0					
				3	142	10	3	0	0	26	11	1	2	0	19	4	0	8	3	0		
				Total	330	52	8	9	0	209	61	8	3	0	20	5	0				306	399
Basic electric arc, special low-S casts	BEA3	3·8	46	1	46	11	3	2	0	152	6	4	3	2	1	0	0					
			44	2	31	13	1	0	0	86	7	2	0	0	0	4	0					
			...	3	25	1	1	0	0	47	11	3	0	1	11	7	3	9	0	0		
				Total	102	25	5	2	0	285	24	9	3	3	12	11	3				350	134
	BEA4	5·9	34	1	66	19	4	3	0	145	34	3	0	0	9	5	1					
			36	2	72	29	9	3	0	185	20	7	0	0	3	2	2					
			26	3	30	9	4	3	0	41	13	2	0	0	7	5	0	13	0	0		
				Total	168	57	17	9	0	371	67	12	0	0	19	12	3				484	251
	BEA5	7·4	32	1	34	11	4	0	1	297	23	10	0	0	1	4	0					
			46	2	29	6	5	2	0	93	13	7	2	0	0	0	1					
			...	3	62	2	2	2	0	38	12	8	2	0	3	0	0	7	0	2		
				Total	125	19	11	4	1	428	48	25	4	0	4	4	1				514	160
Basic electric arc, CaSi-deoxidized	BEA6	14·5	...	1	23	31	30	1	1	147	53	20	0	1	0	0	0					
				2	52	36	20	4	0	47	14	4	3	0	2	2	2					
				3	46	30	11	1	0	30	10	2	0	0	2	0	1	7	0	1		
				Total	121	97	61	6	1	224	77	26	3	1	4	2	3				340	286
	BEA10	26·2	56	1	117	31	4	0	0	16	8	1	0	0	0	0	0					
			68	2	124	69	12	2	0	75	20	6	0	0	0	0	0					
			66	3	324	26	6	0	0	51	6	3	0	0	5	0	0	5	0	1		
				Total	565	126	22	2	0	142	34	10	0	0	5	0	0				191	715
High frequency vacuum-melted	HFV1	22·7	10	1	49	8	0	0	0	190	7	0	0	0	3	0	0					
			8	2	65	12	4	0	0	140	12	0	1	0	2	1	0					
			12	3	95	4	0	0	0	16	2	0	0	0	0	0	0	16	5	4		
				Total	209	24	4	0	0	346	21	0	1	0	5	1	0				374	237
English acid open-hearth	AOH(E1)	20·3	...	1	99	37	18	3	0	31	12	7	1	0	0	0	0					
				2	105	30	17	1	0	36	14	8	1	0	0	1	0					
				3	145	46	17	2	0	28	13	3	0	0	1	0	0	12	0	0		
				Total	349	113	52	6	0	95	39	18	2	0	1	1	0				156	520
Swedish acid open-hearth	AOH(S1)	19·2	58	1	150	41	9	1	0	63	8	1	0	0	1	0	0					
			56	2	103	44	14	2	0	89	21	15	0	0	0	1	2					
			64	3	130	13	3	0	0	55	9	0	0	0	5	0	0	12	0	2		
				Total	383	98	26	3	0	207	38	16	0	0	6	1	2				270	510


a small alumina inclusion
b alumina inclusion
c shower of small glassy silicates associated with MnS
d non-deformed glassy silicate
e silicate stringer showing two glasses
f silicate stringer broken during latter stages of deformation
g silicate inclusion showing two glasses
h large spinel associated with MnS
i silicate associated with MnS
j small silicates associated with TiN
k TiN associated with MnS
a–d
e–h
i–k

16 *Selection of inclusions present* × 750



Counts based on total inclusions observed (×750) in 516 fields representing a total area of ≃ 9 mm²

17 *Relationship between average life and inclusion content*

Analysis of the data obtained showed that, in general, poor rig performance is associated with a large number of alumina and silicate inclusions. Plotting the total number of inclusions of all sizes of these types against the average rig life, as in Fig.17*a*, indicated that correlation existed. On the other hand, at first sight it seemed that the greater the total number of sulphide inclusions the better the average rig life (Fig.17*b*). However, though it is not possible to separate positively the effects of these two types of inclusions, this apparent sulphide effect may only be a reflection of the fact that in the particular steels examined a high sulphide content is always associated with a low alumina and silicate content.

Radiographic examination for segregation and inclusions

A number of samples cut from tested bearings were examined by microradiography to determine the extent and form of Cr segregation, MnS and non-metallic inclusions. The method of preparation of these specimens was similar to that described by Johnson and Andrews.[10] The samples comprised six steels and as far as possible samples giving a low, medium, and high rig test life were selected from each steel. Enlargements ×20 of typical radiographs are reproduced in Figs.18*a–e*.

The general features observed in the photographs are as follows: (a) white streaks shown with both Co and Fe radiation due to Cr segregation, (b) additional white streaks with Co radiation due to MnS inclusions, and (c) black inclusions showing with both Fe and Co radiation due to light inclusions: probably alumina or possibly silicate.

Comparison of the radiographs of the various steels showed that casts BEA3, 4, and 5, which gave a very poor rig performance, had the largest areas of alumina and heaviest segregation; a typical example of the structure of one of the lowest life members of these casts is shown in Fig.18*a*. These steels also contain a considerable amount of MnS. On the other hand, the casts which gave a better average performance were generally free from any relatively large alumina or silicate inclusions, although in some cases there was still heavy segregation; Fig.18*b* shows an example of a specimen which gave a comparatively high life.

If the samples with varying lives from the same steel were compared it was again found, in general, that the test specimens with the shortest life contain the highest number of alumina inclusions; Figs.18*c–e* show typical examples of the structure of low, medium, and high life members of cast BEA10, which gave the best rig performance of any of the steels tested. It will be noted that this steel is comparatively free from Cr segregation and alumina or silicate, but contains a considerable amount of MnS. The heterogeneity in the distribution of inclusions observed in this cast was typical of all the other casts examined.

Generally the results obtained by radiographic examination substantiate the view formed on the basis of metallographic work, namely that alumina inclusions are detrimental to life and that a low content is associated with a high number of MnS inclusions, which, in themselves, do not appear to affect the performance. In the case of casts HFV1 (Fig.18*b*) and BEA3 (similar to Fig.18*a*), however, there did appear to be some discrepancy between the results given by the two types of examination with regard to the number of alumina inclusions observed. Radiographic examinations showed HFV1 to be cleaner and BEA3 to be dirtier than indicated metallographically. The microradiographs, however, taken at a magnification of ×20 only reveal the larger inclusions present, and it will be noted from Table IV that cast HFV1, although containing on average a large number of small inclusions, is virtually free from any alumina inclusions greater than 0·004 mm in width. On the other hand, cast BEA3 contains a comparatively high content of the larger sizes of this type of inclusion. Another point in connexion with cast BEA3 is that as this material contains massive segregates of inclusions there will be differences from one specimen to another as, in fact, has been shown by the two samples examined radiographically.

Inclusion counts at failure

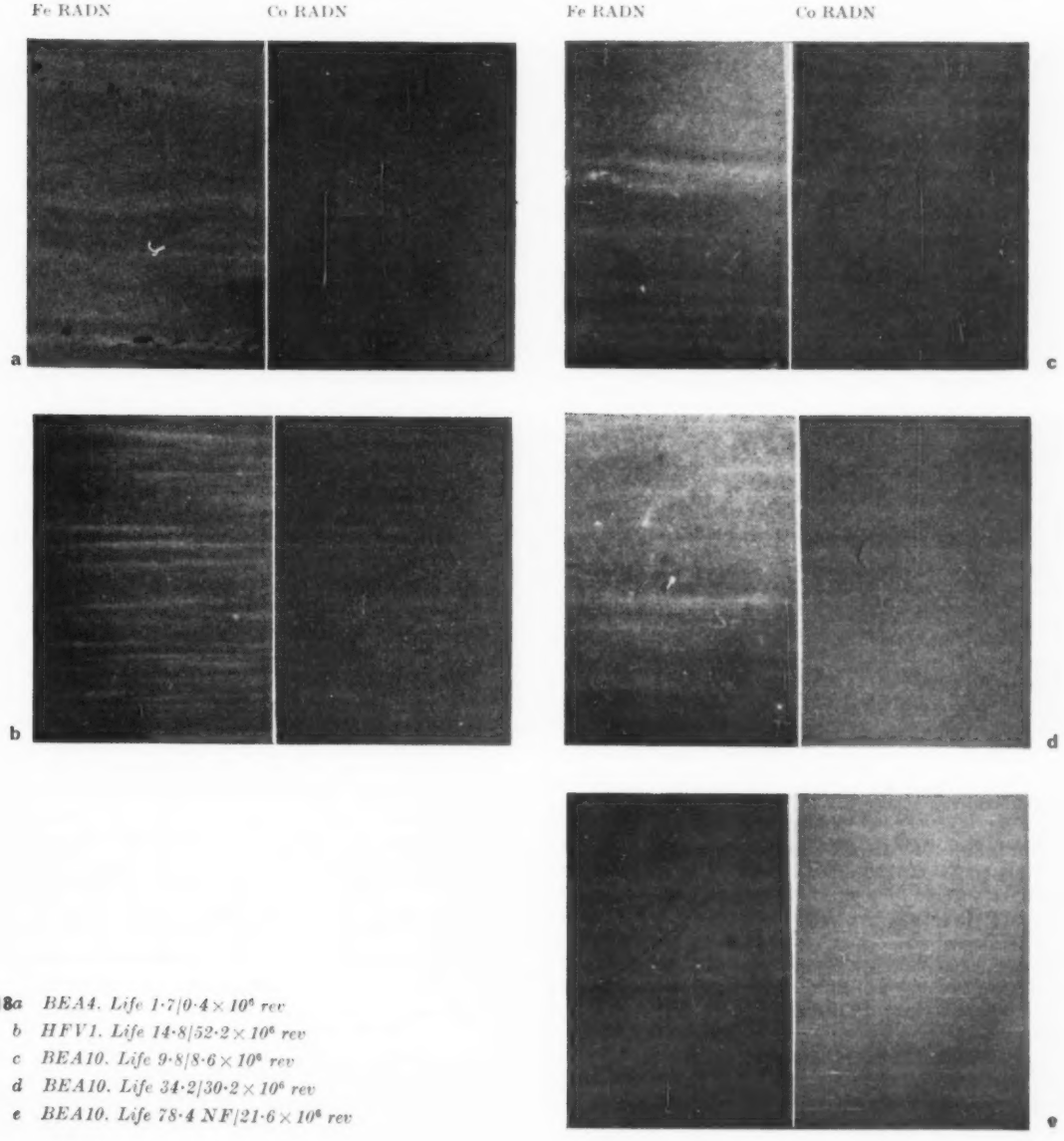
Because rig performance appeared to be associated with the total number of alumina and silicate inclusions and because a heterogeneous distribution of inclusion was suspected as instanced by the marked difference in the lives obtained on a single disc tested on each side in the laboratory rig, it was decided to make inclusion counts on a section taken through the actual failure and to confine the count to material immediately adjacent to the track. Since, in the case of the experimental flat type of specimen, it has been calculated that the maximum shear stress occurs at a depth of 0·0039 in. below the surface, it was originally intended to confine the count to inclusions between the surface and a depth of 0·005 in. so that material subject to the highest stress values only was included. This proved to be impossible, as only 60–70 fields could be obtained instead of the 167 fields required for the detailed count which had been standardized. (This number of fields is slightly lower than that originally used but the change was made in order that the actual area of the specimen examined equalled 3 mm².) Material to a depth of 0·01 in. below the surface was therefore explored, although as a matter of interest the number of inclusions in the surface area was included for comparison. The procedure for measuring and classifying inclusions was the same as that previously used.

The materials chosen for this work included two vacuum-melted and two air-melted steels, casts HFV1 and HFV2, and BEA1 and BEA10 respectively. These steels showed a wide range of lives and also the average lives varied significantly. Specimens were selected from each steel to give the widest possible life scatter and the results of the inclusion counts obtained are given in Table V. It was found that in most cases the

results of counts covering a depth of 0·010 in. agreed with those confined to material between the surface and a depth of 0·005 in., and can thus be regarded as representative of the material which is subject to the greatest level of stress during testing.

The majority of the inclusions observed were graded as class O, and only in a small number of specimens were any inclusions found which were greater than 3 mm in width at a magnification of ×750. This made it impossible to obtain a reliable assessment of the effect of size of inclusion.

In the first attempt to find some correlation between life and inclusion content the data was examined without regard to size of inclusion. The total number of each type of inclusion present was compared with the corresponding life values; and combinations of the various types, particularly those labelled 'non-deformable', were also considered. This failed to show any consistent effect associated either with sulphides or with the total number of all the types of inclusions whether only one steel series was considered or the four series as a whole. Once again the combination alumina and silicate seemed to be showing an effect and its relationship with life is given in Fig.19; this is considered to be a reasonably good correlation in view of the uncertainties in determining both the life and inclusion count values. The unsatisfactory feature of this relationship is that there is a difference in the life values associated with any particular count for the air-melted and vacuum-melted steels, the air-melted steels giving a longer life for a given inclusion content. It appeared, therefore, that some other factor must be causing a reduction in the life of the vacuum-melted steels and a reappraisal of the data focused attention

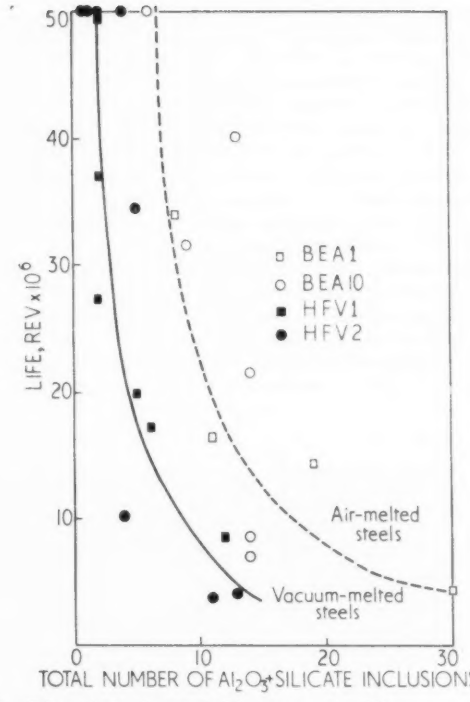


18*a* *BEA4. Life 1·7/0·4 × 10⁶ rev*
b *HFV1. Life 14·8/52·2 × 10⁶ rev*
c *BEA10. Life 9·8/8·6 × 10⁶ rev*
d *BEA10. Life 34·2/30·2 × 10⁶ rev*
e *BEA10. Life 78·4 NF/21·6 × 10⁶ rev*

TABLE V Inclusion counts at position of failure

Steel quality	Cast	Bearing life, rev $\times 10^6$	Sulphides 0	1	2	3	Silicates 0	1	2	3	Alumina 0	1	2	3	TiN 0	1	2	Total inclusions All sulphides	Al_2O_3+ Silicates 0	1	2	3	Total	Al_2O_3 0	1	2	3	Total	Al_2O_3 +Sil. +TiN/2	All types
Basic electric arc, standard practice	BEA1	4·3	157	10	6	1	6	4	3	0	11	6	0	0	0	0	0	174	17	10	3	0	30	17	10	3	0	30	30	204
		14·4	133	15	3	0	5	1	0	0	6	6	1	0	0	0	0	151	11	7	1	0	19	11	7	1	0	19	19	170
		16·7	124	12	0	0	6	0	0	0	4	1	0	0	0	0	0	136	10	1	0	0	11	10	1	0	0	11	11	147
		34·0	107	17	0	0	2	1	0	0	3	2	0	0	1	0	0	124	5	3	0	0	8	6	3	0	0	9	8	133
Basic electric arc, CaSi-deoxidized	BEA10	7·1	155	37	4	1	1	3	1	0	7	1	0	0	0	0	0	197	8	4	2	0	14	8	4	2	0	14	14	211
		8·5	89	16	2	1	0	1	2	1	10	1	0	0	2	0	0	108	10	2	2	0	14	12	2	2	0	16	15	124
		21·5	105	5	2	1	1	2	0	1	3	5	0	0	0	0	0	113	4	7	2	1	14	4	7	2	1	14	14	127
		31·6	135	25	12	0	2	0	0	0	3	3	1	0	0	0	0	172	5	3	1	0	9	5	3	1	0	9	9	181
		40·1	113	14	2	0	2	3	1	0	5	2	0	0	0	0	0	129	7	5	1	0	13	7	5	1	0	13	13	142
		62·5NF	115	22	3	0	1	0	2	0	1	1	1	0	0	0	0	140	2	1	3	0	6	2	1	3	0	6	6	146
High-frequency vacuum-melted	HFV1	8·6	60	1	0	0	0	0	0	0	10	2	0	0	5	4	1	61	10	2	0	0	12	15	6	1	0	22	17	83
		17·3	37	1	0	0	0	0	0	0	6	0	0	0	5	5	0	38	6	0	0	0	6	11	5	0	0	16	11	54
		19·9	46	0	1	0	1	0	0	0	4	0	0	0	8	6	0	47	5	0	0	0	5	10	1	1	0	12	9	59
		27·3	43	0	0	0	0	0	0	0	2	0	0	0	5	4	0	43	2	0	0	0	2	7	4	0	0	11	7	54
		37·2	48	0	0	0	0	0	0	0	2	0	0	0	3	5	0	48	2	0	0	0	2	5	5	0	0	10	6	58
		50·3	35	1	0	0	0	0	0	0	1	1	0	0	8	4	0	35	1	1	0	0	2	9	5	0	0	14	8	49
		68·9NF	51	1	0	0	0	0	0	0	2	0	0	0	6	0	0	51	2	0	0	0	2	10	6	0	0	16	9	67
	HFV2	3·9	42	0	0	0	0	0	0	0	7	4	0	0	10	4	0	42	7	4	0	0	11	17	8	0	0	25	18	67
		4·2	64	5	0	0	0	0	0	0	13	0	0	0	17	10	0	69	13	0	0	0	13	30	10	0	0	40	27	109
		10·2	55	2	0	0	0	0	0	0	4	0	0	0	15	3	0	57	4	0	0	0	4	19	3	0	0	22	13	79
		34·7	25	2	0	0	0	0	0	0	3	1	0	0	12	3	1	28	4	1	0	0	5	16	4	1	0	21	13	49
		60·5NF	52	1	1	0	1	0	0	0	0	0	0	0	16	7	1	54	1	0	0	0	1	17	7	1	0	25	13	79
		129·8NF	89	0	0	0	3	0	0	0	0	1	0	0	8	4	0	89	3	1	0	0	4	11	5	0	0	16	10	105
		135·6NF	53	0	0	0	0	0	0	0	1	0	0	0	27	7	0	53	1	0	0	0	1	28	7	0	0	35	18	88

NF indicates specimen did not fail



19 *Effect of alumina and silicate content on life*

on the comparatively large number of titanium nitride group inclusions in the vacuum-melted steels.

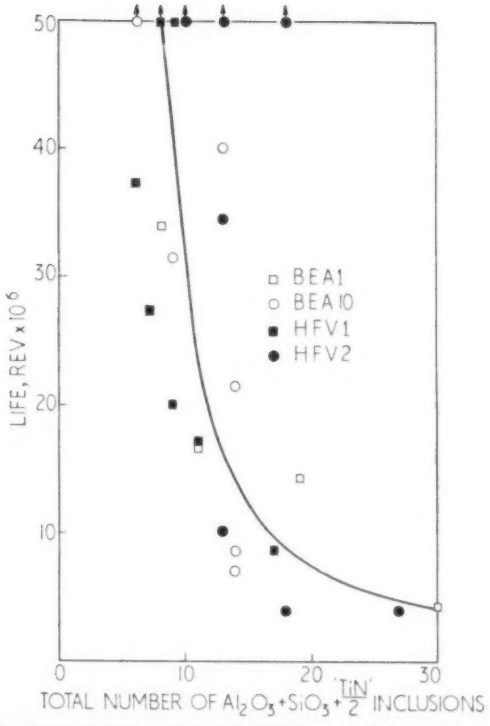
If the number of all sizes of titanium nitride group inclusions is added to the totals of alumina and silicates, it is found that, for a given level of inclusions, the vacuum-melted steels now show a higher life than the air-melted steels. This suggests that titanium nitride group inclusions affect the life, but to a lesser extent than alumina and silicate inclusions, and, in fact, the best correlation seemed to be obtained with the numerical combination of alumina+silicate+TiN/2 group inclusions. This relationship is illustrated in Fig.20 where a single curve can reasonably be drawn through all the points obtained from 24 specimens representing different steelmaking techniques.

This finding led to a statistical analysis to determine whether, in fact, the best relationship had been found and to test its significance. Processing the data on a computer revealed that life is very significantly correlated with alumina (class O) content. The relationships previously suggested all contain this factor but the statistical analysis showed that, although these relationships are significant, the correlation coefficients are not as high as with alumina alone. The curve drawn in Fig.21 represents statistically the average curve for the life values plotted against the number of alumina (class O) inclusions, and it is interesting to note that this forms a rectangular hyperbola such that

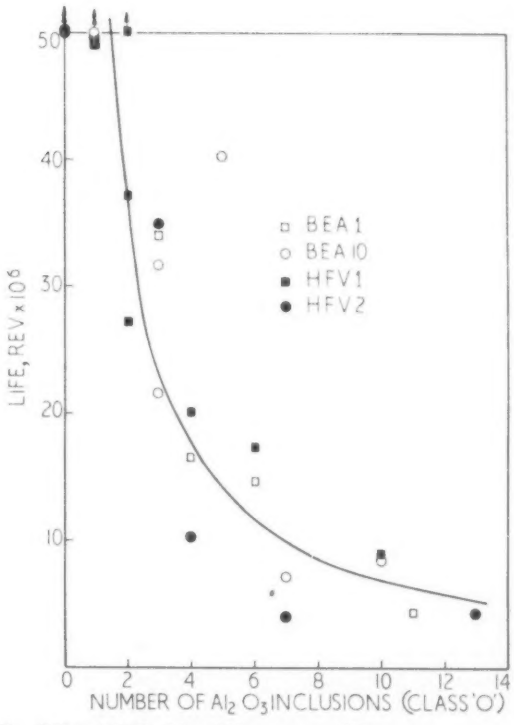
$$\text{Life} = \frac{68 \times 10^6}{\text{Number of alumina (class O) inclusions}}$$

GENERAL DISCUSSION

The main purpose of the work that has been carried out was to establish the effect of steelmaking practice



20 *Effect of* Al_2O_3 *+ silicate and* 'TiN' *inclusions on life*



21 *Effect of* Al_2O_3 *(class 'O') content on life*

on bearing performance. A simple laboratory rig was designed to simulate conditions in bearing service and to establish the value of this test attempts were made to align its results with those of manufacturers' bearing tests and conventional rotating beam fatigue tests. The former has been less satisfactory than would have been expected from the similarity of the two types of test and the failures arising from them, but as comparisons have only been completed on five casts, and as in each case it is felt that insufficient attention had been paid to ensure parallel sampling for the two tests, further work is proceeding. In the case of the rotary bending tests the result was happier under specific conditions of stress. It is against this background that the results have been assessed for their usefulness in determining the most satisfactory steelmaking practice.

The most important measure of a bearing steel from the manufacturers' point of view is the low-life performance; Swedish acid OH and CaSi-deoxidized electric arc casts as judged on the basis of the laboratory rig test are the best in this respect. On average life performance, however, these steels show no advantage compared with other air-melted steels with the exception of the 'neutral OH' steel where only one cast was tested and an early series of experimental low-sulphur electric arc casts. In the case of vacuum-melted steels the relative performance differed according to the method of assessment. In these steels scatter between individual results is much greater than that of air-melted steels so that although average life is relatively high, the low-life performance is poor. There is some indication, however, that this difference in behaviour becomes less marked as the overload conditions in the test become less severe so that under normal bearing operating conditions they could perform better than other types.

In making this assessment, any possible effects of ingot size have been ignored. This is one aspect which it is intended to explore in a future programme.

Rotary bending tests have shown considerable differences between the steels, not only in limiting fatigue stress values but also in the performance at higher stress levels. Published figures[4, 5, 7] on 1%C–Cr steel also show considerable variation; for example, for air-melted steels Styri[4] reports a limiting fatigue stress value of about 52·9 tons/in², whereas Frith[7] gives a value as low as 35·7 tons/in². Regarding the effect of steelmaking practice it has been reasonably well established in this and other investigations[4, 7, 8] that vacuum-melting increases the limiting fatigue stress value. In air-melted steels the influence of steelmaking practice, however, is uncertain, although Frith[7] claims that the fatigue strength of OH steels is higher than that of electric furnace material. In the authors' tests the OH casts tend to show less scatter in limiting fatigue stress value compared with the basic electric arc steels tested, and lie at the top of the scatterband obtained for the basic electric arc material. There is no doubt that good electric arc steel at least matches OH quality and that modifications in electric arc steelmaking practice can reduce the scatter and restrict it to the upper part of the band.

Little attention has previously been given to the performance under rotary bending conditions at higher stresses. This is a function of the slope of the S–N curve, and it has been shown that this varies considerably for different steels, and is also largely

independent of limiting fatigue stress value. The greatest difference in slope occurs between vacuum-melted and air-melted steels. All the vacuum-melted steels give a very shallow slope with the result that steels of this type tend to lose their advantage compared with air-melted steels as the stress increases. In the present series of tests in fact, the two qualities give similar endurance values with stresses between about 57 and 60 tons/in^2. Recent US work[11] on SAE4340 quality steel has shown a similar effect and in this case there is no difference in the endurance value of air-melted and vacuum-melted steels at stresses of 62 tons/in^2.

Many previous attempts have been made to explain the difference in performance under rotary bending conditions in terms of inclusion content. The results obtained, however, are very conflicting; for example, Hyler, Tarasov and Favor[12] report no correlation between fatigue strength and size or location of inclusions, whereas Stulen, Cummings and Schulte[13] report that the fatigue strength is strongly dependent on the size and location of inclusions. In connexion with the differences in slope of the S–N curve the latter workers[11] also suggest that there is a rapid change with increasing stress, from sensitivity to (perhaps) the effect of a single dominant inclusion at low stresses, to not only some dominant inclusion but also other smaller inclusions. These workers obtained particularly interesting results in the case of a vacuum-melted steel, which suggested that although no measurable inclusions were observed in some of the specimens examined, fracture nuclei could be identified and counted. They suggested further that inclusions of submicroscopic size or some other submicroscopic stress-raisers are present. On the basis of these counts it was found that as the stress level increased, the number of nuclei in vacuum-melted steel also increased faster than in the corresponding air-melted steel.

If a correlation exists between bearing rig life and inclusion content at the position of failure, as well as a relationship between bearing life and endurance under rotary bending conditions, it follows that there should be a correlation between inclusions and rotary bending performance. The limited number of tests which have been carried out, however, have failed to confirm this, and it is thought that in this form of test, position rather than size and/or number of inclusions is the dominating factor. No evidence has been obtained of any increase in fracture nuclei with increase in stress and so far no satisfactory explanation can be given for the difference in slope of the S–N curves.

The failures previously to establish any definite correlation between fatigue properties determined under rotary bending conditions and bearing test performance probably stem from attempts to do so without regard to the conditions under which the bearing tests have been carried out. The authors' results suggest that as the effective stress in the bearing test increases, the bending stress required to provide a related endurance value will also increase, and only in cases where the bearing stress is comparatively low will the limiting fatigue stress value provide any indication of bearing performance. For the stress conditions peculiar to a particular bearing test there will be a specific level of bending stress which will give an average endurance value related to the average bearing performance, and because of differences in the slope of the S–N curve comparisons will be invalid at any other stress level.

It is not possible to calculate the bending stress corresponding to a given bearing load or to suggest any positive explanation for obtaining, for example, a correlation in the case of the authors' rig, with endurance values at a stress of ± 58 tons/in^2. It must be assumed, however, that this particular rotary bending stress produces stress conditions which show a similar effect to those imposed by the 750-lb load applied in the case of the bearing test.

Much further work is required before this correlation can be accepted, but if it is confirmed the rotary bending test will prove of considerable value as a means of obtaining a preliminary indication of the properties of bearing steel. The advantages of this form of test are obvious, and in particular, it will enable a relatively quick assessment to be obtained of the likely behaviour of a material under different bearing operating conditions.

The investigation into the effect of inclusions forms one of the most interesting features of the work described. In the case of the four steels that were examined in detail, it has been possible to find a correlation between laboratory rig life and inclusion content. So far as the authors are aware this is the first time that any quantitative relationship between life and any other factor has been put forward although Frith[3] and other workers have obtained evidence of similar relationships on a qualitative basis. At this stage it would be misleading to over-emphasize this correlation, in spite of its statistical significance, because of the limited data available. It is based on the examination of only four relatively clean steels and all the tests have been carried out under one particular set of conditions. The hope is that confirmation will come in due course from the further work in hand so that it will ultimately be possible to relate the life of all bearings to inclusion content. The results which are now being obtained from a preliminary examination of a number of failed manufacturers' bearings, tested under commercial rig conditions, have encouraged this hope. Certainly the inclusion content is the only factor that has been investigated which appears to be related to life.

Although in those steels which were examined in detail the life of any individual specimen is most significantly correlated with the number of alumina inclusions greater than $1\frac{1}{2}$ mm in width at a magnification of $\times 750$, which were present immediately adjacent to the failure, it so happens that alumina inclusions of this size predominate, so that the evidence does not eliminate the possibility that other similar types of inclusions, such as silicates and TiN, will not have a similar effect. In fact, if the comparatively small number of these latter types of inclusion is added to the total alumina the significance of the correlation is only slightly reduced. The effect of size is not clear since in the main all the inclusions present are small. The evidence does seem to suggest that marked influence on life is due to the alumina, silicate, and inclusions of the titanium nitride group, i.e. the types which are not deformed at ordinary rolling temperatures. Frith[3] suggests that this is because end-cavities are produced in rolling owing to the difference in plasticity between the inclusion and the

parent metal. No end-cavities have, however, been observed in the present series of tests, but since the majority of the inclusions are small their existence is not ruled out, and it is possible that they might be revealed by more detailed radiographic examinations or microscopical examination at higher magnifications. Sulphides that are plastic at rolling temperatures would not be expected to affect the structure in this way, which is in agreement with the results of this work where sulphide inclusions did not appear to be detrimental.

It is not considered that all the deleterious types of inclusions will have an equal influence, but it is suggested that the life is governed by the occurrence of one or more of these at the position of maximum stress. The criterion thus becomes that of the probability of these inclusions occurring at critical positions relative to the track, which will be related to the total number of inclusions present.

Although the establishment of the life/inclusion relationship does offer the interesting prospects that have been propounded, its practical application may prove to be much more difficult. In the first place the relationship has only applied when the inclusions adjacent to and immediately below the failure have been counted. There is little doubt that segregation of inclusions, perhaps in small pockets in the form of clouds, occurs, and this could be the cause of the low-life results on vacuum-melted steel. It has yet to be established whether this limitation of the position of the inclusion count can be overcome by some system of sampling. It certainly seems that this may have to be quite extensive and very carefully controlled to enable a reasonable assessment to be made of the 'scatter' of inclusion count. Exploratory work is planned on the sampling problem though it is not yet seen how the inclusion heterogeneity can be influenced in the steelmaking. Secondly, since only certain types of inclusions seem to be deleterious it is essential that the method of counting is capable of identifying them. Standard types of inclusion counts do not meet this requirement in sufficient detail and a count of the type used in the present work, with which it has been found difficult under research conditions to get reproducible results, is even less readily and accurately applied in works laboratories as a means of production control. Lastly, since there are indications that very small inclusions can have as much influence on life as large ones, and perhaps more, possibly through their wider distribution and consequently higher probability of being present in a highly stressed area, the added complication of having to carry out assessments at relatively high magnifications ($\times 750$) in order to detect them has to be faced.

Further simplification is certainly indicated, so that this work can be converted into a practical tool that will be useful in the control of steelmaking practice.

SUMMARY

1. A fatigue rig designed to simulate in simple form the conditions applying in the case of bearing endurance test rigs, and which produces the same type of bearing failure, has been developed.

2. Tests have been carried out with the main object of investigating the effect of differences in steelmaking and basic electric arc practice; acid, basic, and 'neutral OH'; and high-frequency vacuum-melted steels have been compared. In the case of basic electric arc steel the test has been used to assess the effect of modifications in deoxidation practice. These tests have indicated that the following may be significant:

(i) when assessed on the basis of L_{10} performance, there is little difference between basic electric arc and Swedish acid OH steels. The performance of these steels is superior to other qualities, including high-frequency vacuum-melted

(ii) when assessed on the basis of average life, high-frequency vacuum-melted steels give a superior performance compared with air-melted qualities. OH and well-made basic electric arc steels give similar results, although the scatter from cast to cast suggests that the latter are more susceptible to steelmaking variables.

3. The same steels have been used for bearing and rotary bending tests and the performances given by the different test methods have been compared. On the basis of these tests the following points have been noted:

(i) the correlation between rig and bearing tests is less satisfactory than was expected. There is evidence to suggest, however, that this may be due to the unforeseen influence of sampling

(ii) under the conditions of testing employed in the rig tests, there is no correlation between rig test behaviour and limiting fatigue stress under rotary bending conditions. However, there is a relationship with the endurance at one specific stress level. The latter may vary according to the load used in the rig test

(iii) There is some doubt regarding the value of short-time high-stress tests as a means of assessing material to meet service requirements.

4. A comprehensive metallurgical examination of the test specimens was carried out and this led to a detailed investigation of the form and type of inclusions present. The following trends were indicated:

(i) there is no correlation between rig test performance and any material variable other than non-metallic inclusions. In establishing this, a special inclusion counting technique was developed, no indication being obtained by means of standard methods

(ii) this new method of inclusion counting shows a variation in inclusion content in different positions in the same steel, and, for this reason, it was necessary to make assessments in the neighbourhood of the failure

(iii) under the above conditions, there is a quantitative relationship between 'brittle' type inclusions and life.

5. Work is being continued in the hope of being able to develop a practical tool for the control of steel quality.

ACKNOWLEDGMENTS

The authors wish to thank the Directors of Samuel Fox and Co. Ltd and Mr F. H. Saniter, Director of Research at The United Steel Companies Ltd, for permission to publish this paper. They acknowledge the encouragement and assistance they have received in carrying out the work from their colleagues in the research laboratory and at the works. They are also grateful for the co-operation they have received from the Crucible Steel Company of America and the English Steel Corporation Limited, both of which supplied test material; Tubes Limited (Desford) who assisted in the production of test material; the Skefko Ball Bearing

Company Limited who supplied the original idea, provided the samples of Swedish steel, and carried out co-operative bearing tests; Hoffman Manufacturing Company Limited who provided the original rig design and Ransome and Marles Bearing Company Limited who conducted co-operative tests.

REFERENCES

1. T. L. Robinson: *Trans. ASST*, 1927, **11**, 607–618.
2. A. S. Jameson *et al.*: *Iron Age*, 1951, **167**, (14), Apr. 102–107.
3. P. H. Frith: 'Fatigue tests on rolled alloy steels made in electric and open-hearth furnaces', *ISI Spec. Rep.* 50, Oct. 1954.
4. H. Styri: *Proc. ASTM*, 1951, **51**, 682–700.
5. L. P. Tarasov and H. S. Grover: *Proc. ASTM*, 1950, **50**, 668–698.
6. W. E. Bardgett: In discussion, *JISI*, 1955, **181**, 328–329.
7. P. H. Frith: *JISI*, 1955, **180**, 26–33.
8. G. Sachs *et al.*: 'Tension, compression and fatigue properties of several steels for aircraft bearing applications,' *ASTM* preprint 73, 1959.
9. J. Leiblein and M. Zelen: *J. Res.*, 1956, Nov, 273–316.
10. W. Johnson and K. W. Andrews: *Iron Steel*, 1958, **31**, 437–444.
11. H. N. Cummings *et al.*: *Trans. ASM*, 1957, **49**, 482–516.
12. W. S. Hyler *et al.*: *Proc. ASTM*, 1958, **58**, 540–551.
13. F. B. Stulen *et al.*: 'Relation of inclusions to the fatigue properties of high-strength steels', International Conference on Fatigue of Metals, Inst. Mech. Eng., London, 1956.

STAL *in English*

Number 8 of the 1960 series of *Stal in English* has been published and subsequent issues will appear at about monthly intervals. Principal contents of nos.9 and 10 are given below. Full details of subscriptions to *Stal in English* are available from the Secretary of The Iron and Steel Institute.

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Influence of size of sinter mix components on some sintering-process factors

STEELMAKING

A rational method of deoxidizing steel with aluminium in the ladle
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Use of furnaces with highly refractory basic roofs for improving quality of chrome steel

ELECTROMETALLURGY

Treatment of ball-bearing steel with synthetic slag

FERROALLOYS

Reducing the cost of ferrosilicon made in electric furnaces

ROLLING AND TUBE PRODUCTION

Trends in blooming mill developments

A vacuum rolling mill

The mechanism of metal destruction during transverse rolling

SMALL COMPONENT PRODUCTION

Methods of increasing output of patenting furnaces

Marker movements in the oxidation of iron and some other metals

R. F. Tylecote and T. E. Mitchell

SYNOPSIS

Experiments carried out on iron and some non-ferrous metals have shown that platinum wire markers can be moved inwards with the metal interface or outwards with the oxide/air interface according to the diffusion mechanism, film plasticity, and the adherence of the film to the metal substrate. In the case of iron this adherence can be modified by providing sinks for the vacancies forming at the metal/oxide interface by drilling holes in the metal parallel to this interface. The work essentially supports the mechanism propounded by Dunnington, Beck, and Fontana (Corrosion, 1952, **8**, 2). 1870

INTRODUCTION

THIS PAPER IS PART of a series on various aspects of the problem of adherence of oxide films on relatively pure metals. Although a great deal of work has been devoted to the study of the oxidation of iron by means of inert markers, no definite conclusions have been drawn regarding the mechanism of oxidation, which are applicable over an extended temperature range. Pfeil used a marker of chromic oxide, and found a porous oxide layer between the marker and the metal surface after oxidation for long periods between 850° and 1050°C.[1,2] Engell and Wever[3] showed that markers remained in contact with the iron surface during oxidation between 600° and 800°C, but were to be found within the film after oxidation at temperatures above 850°C. This led them to conclude that below 800°C the transport mechanism was exclusively the outward movement of metal ions, although at higher temperatures some inward diffusion of oxygen was taking place. Davies and his colleagues,[4] using a radioactive silver tracer, showed that oxidation of iron to wüstite was solely by the outward movement of iron ions up to 1090°C. Sachs[5] has questioned the validity of Davies' experiments, and has suggested that the markers were not inert.

Recent work by Juenker,[6] and others, has confirmed the observation of Engell and Wever that markers move into wüstite films at high temperatures. Additional work by Mackenzie and Birchenall[7] and one of the present authors[8] showed that pure wüstite films have some degree of plasticity, which, in the case of a sheet specimen, would allow them to follow up the shrinking metal and maintain contact. On the other hand, this appears to be inhibited by the formation of thin superficial films of Fe_2O_3 and Fe_3O_4, which normally form at the higher temperatures. Juenker and his colleagues suggested that the movement of markers into the film at high temperatures was due to the rigidity of the higher oxides which prevented the wüstite from maintaining contact with the metal, leaving a void. This void was filled by oxidation of metal at the oxide/metal interface so leaving the marker well within a dense film. The mechanism of inward oxygen diffusion was left undecided.

On the other hand, Dunnington *et al.*[9] have put forward a different view. This is based on the co-operation which undoubtedly exists between thin films situated on opposite sides of the metal specimen. It is suggested that vacancies created during oxidation diffuse back into the metal producing a vacancy gradient within it. At the start of oxidation this gradient is steep, and contact between metal and oxide can be readily maintained without the formation of holes. Later it becomes less steep and vacancies tend to congregate on the metal/oxide interface leading to separation.

When separation occurs on one surface, the gap so formed acts as a sink for the vacancies collecting on the other side, the gradient is increased and flow maintained, so permitting the other side to remain in contact until all the metal is consumed.

According to Dunnington, thick specimens will reduce the vacancy gradient, and above a certain thickness this will become too small to nourish the oxidation reaction, so leading to a 'Pfeil-type' porous layer, where repeated failure of the oxide to adhere takes place in one spot. In this case the amount of metal supplied to the scale decreases steadily and large amounts of the higher oxides are formed.

The present work was undertaken with the object of testing the Dunnington mechanism, and following the oxidation process by means of inert markers, so as to try and determine which of the above mechanisms is operative at any one time, and its influence on adherence. In order to test the validity and interpretation of the marker movements on iron, a number of other metals of known oxidation characteristics were oxidized under conditions similar to those for iron. Copper, titanium, and zirconium were chosen, since copper[10] has been shown to oxidize by a mechanism

Manuscript received 7 October 1960.

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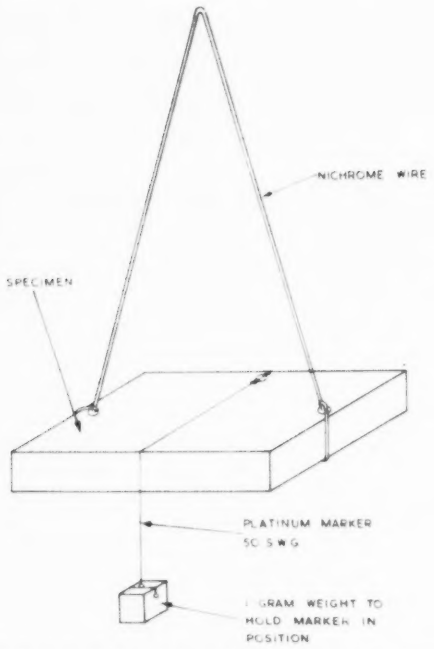


1 *Method of attachment of marker and suspension of specimen*

TABLE I Results of the oxidation of artificial cavity specimens

Iron APC 4/0 micro polish. 0·123 in. thick

Specimen	Oxidation Temp., °C	Oxidation Time, h	Thickness after oxidation, in. Film 1	Film 2	Metal	Hole dia., in. Initial	Final
1 Cavity	950	22	0·075	0·040	0·050	0·045	0·055
1a Blank	950	22	0·045	0·035	0·065	...	...
2 Cavity	800	22	0·026	0·027	0·101	0·045	0·051
2a Blank	800	22	0·027	0·027	0·091	...	...
3 Cavity	750	22	0·0143	0·0143	0·106	0·045	0·046
3a Blank	750	22	0·0143	0·018	0·106	...	...
4 Cavity	800	22	0·0285	0·0285	0·108	0·040	0·045
4a Blank	800	22	0·0285	0·0285	0·093	...	...

involving the outward movement of cuprous ions, titanium is generally thought to oxidize by the inward diffusion of oxygen[11] (although Kinna and Knorr,[12] and Hurlen,[13] disagree with this), and zirconium would be expected to behave similarly to titanium. A Cu–1%Al alloy was also used, for comparison with pure copper.

MATERIALS USED AND EXPERIMENTAL PROCEDURE

Materials

The iron used was Swedish charcoal iron APC with the following composition: 0·017%C; 0·001%Si; 0·006% Mn; 0·007%S; 0·002%P; Cu, Co, Ti, Ni, Cr, Mo, V, Al, Sn, Pb, As, and B all less than 0·01% by weight.

The composition of the non-ferrous metals was as follows: Copper NPE; O_2, 0·030%; Fe, Ni, and Pb, 0·0005%; P, nil; Sb <0·0002% if any; As, <0·002% if any. The zirconium had a purity of 97·7%, the principal impurities (excluding hafnium) being 0·1%O_2 and 0·1%C. The titanium contained about 0·1%O_2, 0·02%N_2, 0·006%H_2, 0·02%C, and 0·08%Fe.

Preparation of specimens for oxidation

The specimens consisted of small pieces of strip 0·040–0·100 in. thick with three 0·03-in. dia. holes drilled for the attachment of a marker and support during oxidation (Fig.1). Since the thin material would have been completely oxidized at higher temperatures, the thicker material was used at temperatures above 800°C. In order to investigate the effect of specimen size on the oxidation of iron, specimens 0·18 and 0·36 in. thick were oxidized at 900°C for 16 h.

The iron specimens were degreased by swabbing with toluene and then vacuum annealed at 900°C for ½ h which reduced the hardness to about 75 DPN. They were then mechanically polished on emery paper to grade '000' and then on a revolving polishing pad using a suspension of alumina. Degreasing was carried out by rinsing in successive baths of toluene. The specimens were finally electrolytically polished using a solution composed of 133 ml glacial acetic acid, 25 ml chromic trioxide, and 7 ml distilled water. The time required was 10 min at a current density of 15 amp/dm² using a stainless steel cathode. The temperature of the solution was maintained at 20°C. The apparatus allowed only one side of the specimen to be polished at once, so when one side had been polished the specimen was removed and the polished side coated with wax. The unpolished side was then set to face the cathode and was also polished. The wax was removed in a current of warm air, and after degreasing in toluene the specimen was ready to have a marker attached.

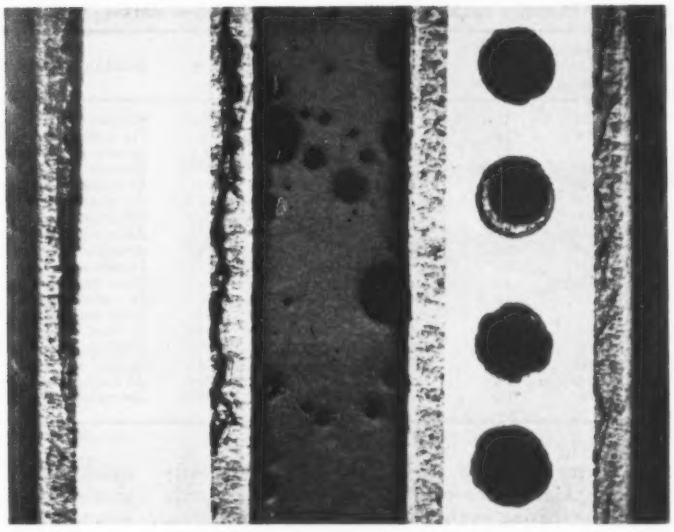
The non-ferrous specimens were similar in dimensions to the iron specimens and the method of preparation was similar except for the final stages. Copper was given a final electrolytic polish using a solution consisting of 700 ml orthophosphoric acid and 350 ml distilled water at a current density of 7A/dm² for 30 min. Titanium was prepared by polishing on selvyt with diamond grit of grades 6; 3; 1; ¼μ; and was then given a light etch in a solution of hydrofluoric acid, nitric acid, and glycerol in the ratio 1:1:2. Zirconium was prepared by polishing with the four grades of diamond grit and finally dipping in 25%HNO_3, which gave a bright surface free from pits.

The markers used were made of platinum wire in two thicknesses: 50 swg (0·001 in.) wire was used at lower temperatures, but it was found that 44 swg (0·003 in.) had to be used at high temperatures where creep caused the thin wire to break. The specimen was supported horizontally by means of a Ni–Cr alloy wire, and the platinum marker was laid across the surface of the plate by attaching one end to the specimen and the other end to a 1 g weight which ensured good contact between the marker and the specimen. The arrangement is shown in Fig.1. This method means that it is only possible to mark one side of the specimen, but it had to be used since the method of looping the wire completely round the specimen caused the wire to break before sufficient tension had been applied to give good contact.

Apparatus used for oxidation

The specimens were supported in a vertical tube furnace, and allowed to oxidize in air supplied by natural convection.

The specimens were given a final degreasing treatment by dipping in successive baths of toluene. A



2 *Comparison of adherence of artificial cavity specimen and a normal specimen of iron oxidized at 800°C* ×7

winch served to raise and lower specimens to and from a predetermined position in the furnace. Each specimen was attached to a silica rod by means of a nichrome wire hook and the silica rod was in turn attached to the winch by means of fine wire.

Wire spokes attached to the silica rod prevented the specimen touching the furnace walls. The thermocouple was introduced through a silica tube and was set so that the hot junction was about $\frac{1}{8}$ in. above the surface of the specimen. In this way, specimens were oxidized at temperatures in the range 750–1000°C for periods from $\frac{1}{2}$ to 65 h. Slow cooling was employed to minimize the possibility of exfoliation due to different thermal contraction coefficients of metal and oxide. The specimens were then mounted and polished metallographically and examined to find the position of the marker.

The mounted specimens were ground on emery papers, finishing with grade '000' using paraffin as lubricant. They were then ground on a revolving pad using alumina powder. After washing, a final polish was given on a selvyt pad using a fine paste of alumina. Grain boundaries in iron oxide were shown up by etching in aqueous 5%O_3 HNor 5%HCl. The Fe_2O_3 was not attacked and the Fe_3O_4 was a lighter colour than wüstite. Thus the three distinct oxide layers were visible, and the thicknesses could be measured.

EXPERIMENTAL RESULTS

Effect of artificial cavities in iron

In order to test the theory of Dunnington and his colleagues a number of 0·123-in. thick iron specimens were made from APC plate. Some of these were drilled with holes 0·040–0·045 in. dia. along the thickness of the specimen (Fig.2). If Dunnington is right it could be argued that these holes would act as sinks for the vacancies being created during oxidation at the metal/oxide interface, and therefore delay exfoliation. For this purpose it was necessary to prevent the holes themselves being oxidized and they were therefore drilled a little short of the end of the specimen and the other end plugged with pieces of iron wire. The specimens were then polished on wet metallographic polishing papers down to a fineness of grade '0000'.

Specimens with and without the cavities were oxidized at 750°, 800°, and 950°C, for 22 h and the results are shown in Table I. At 750°C there was little difference in the behaviour of the two specimens, and the films on both sides of the specimen with cavities were adherent. On the specimen without artificial cavities, the film on one side adhered well, while that on the other was partially non-adherent after oxidation. The film thicknesses were the same all four sides, and the films consisted substantially of wüstite with very little of the higher oxides. This shows that the small amount of exfoliation on the specimen without cavities must have taken place on cooling. The final metal thickness was the same in both cases, and no increase in the hole diameter had occurred, showing that there was little diffusion of vacancies towards the holes.

After oxidation at 800°C there was a marked difference between the specimens. The metal remaining in the specimen containing cavities was 0·101 in. thick, while that in the specimen without was only 0·091 in. in thickness. The holes had increased in diameter from 0·045 in. to 0·051 in. One hole showed signs of oxidation, presumably due to leakage, but this hole was not measurably larger than the others. The films, still substantially the same thickness on both specimens, had adhered well on the specimen with cavities, while on the blank specimen contact was completely broken on one side, and intermittent on the other (*see* Fig.2). This experiment was repeated with similar results, but it was noticed that the holes in the cavity specimen now had a marked ovality, the long axis being normal to the metal/oxide interface.

After oxidation at 950°C, the consumption of metal had gone so far that the holes had been broken into and were themselves heavily oxidized. The metal/oxide interfaee was therefore very irregular, but the thickness of the metal remaining in the cavity specimen was somewhat less than that remaining in the blank. The total film thickness was appreciably greater

TABLE II Oxidation conditions, adherence, and position of marker in scales on iron

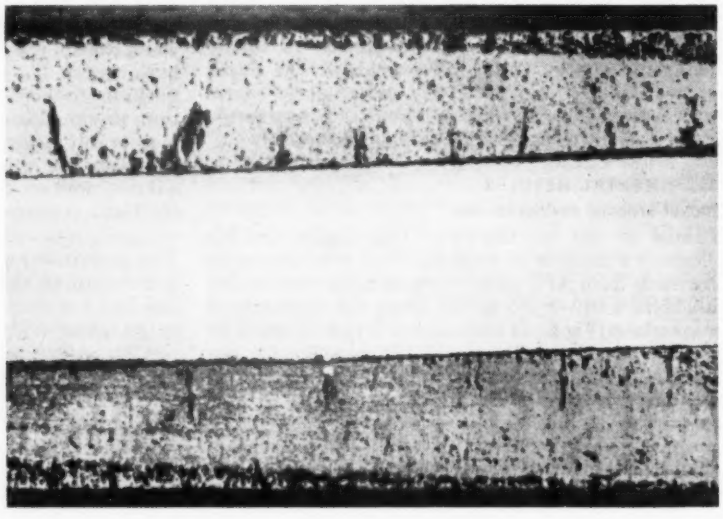
No.	Conditions of oxidation Temp., °C	Time, h	Original metal thickness, in.	Thickness of scale, in.	Position of marker and estimated degree of adherence before cooling
1	750	15	0·040	0·013 + 0·008	On metal/oxide interface of non-adherent side; other side adherent
3	750	18	0·050	0·009 + 0·009	On metal/oxide interface of adherent side; other side non-adherent
4	750	19	0·040	0·021 + 0·009	In non-adherent scale; other side adherent
5	750	20	0·040	0·013 + 0·016	In scale on non-adherent side; other side adherent (Fig.5)
7	750	65	0·040	0·029 + 0·021	In scale on non-adherent side; other side adherent
8	780	24	0·102	0·011 + 0·013	At interface; alternating adherence on either side
6	800	15	0·050	0·026 + 0·017	At interface; alternating adherence on either side (Fig.4)
9	800	15	0·050	0·018 + 0·014	At interface; both sides just adherent in region of marker (Fig.3)
10	800	16	0·050	0·017 + 0·019	At interface; alternating adherence on either side
11	800	36	0·070	0·017 + 0·023	In non-adherent scale; other side adherent
12	830	15	0·042	0·019 + 0·012	Near interface on adherent side; other side non-adherent
13	870	18	0·050	0·032 + 0·034	In scale on adherent side (Fig.6); other side non-adherent
14	900	4	0·050	0·012 + 0·011	Both sides adherent; marker at interface
19	950	17	0·060	0·040 + 0·040	In Pfeil-type scale on adherent side (Fig.7). Other side non-adherent
20	1000	43	0·106	0·050 + 0·050	Pfeil-type scale on both sides; marker in scale
23	900	16	0·18	0·018 + 0·028	In non-adherent scale; other side exfoliated on cooling
25	900	16	0·36	0·022 + 0·014	At metal/oxide interface; both sides exfoliated on cooling
25	900	16	0·37	0·020 + 0·020	At metal/oxide interface; both sides exfoliated on cooling

on the cavity specimen, suggesting that in the early stages of oxidation the cavities had played a part in delaying exfoliation so that outward diffusion of metal ions was maintained for a longer time than with the blank specimen.

These experiments go some way towards supporting Dunnington's explanation. It would appear that at 750°C the size of the cavities on the interface after 22 h is not sufficient to reduce the adherence. Nor is the number of vacancies diffusing in 22 h at this temperature sufficient to enlarge the holes. At 800°C a high proportion of the vacancies have diffused into the cavities provided, thus enlarging them, with the result that adherence has been much improved. At 950°C some improvement has been effected in the early stages by the presence of the cavities, but the long time of oxidation and consequent high metal consumption has largely negatived the initial improvement.

The position of markers in oxide films on iron

The quantitative assessment of adherence raises many difficulties and it has been necessary here to resort to purely qualitative expressions. It would seem that the exfoliation of films is partly caused by the accumulation of vacancies on the metal/oxide interface. This effect increases with time, and provided no sinks are present will result in complete or partial loss of contact. At low temperatures (*c.*750°C), the formation of actual cavities on one or other of the interfaces can in some cases be seen. When loss of contact finally occurs on one interface, the continued adherence of the other side seems to be assured, even after cooling to room temperature. However, when both films stay adherent during oxidation, some weakening of contact between the metal and oxide on these two surfaces seems to occur, and there is therefore more likelihood of exfoliation of one or both sides during cooling. It is not difficult to differentiate between exfoliation during cooling and exfoliation on oxidation, since the latter leads to a restricted outward ion flow and consequent increase in the proportion of the higher oxides at any given temperature. Therefore, in the results given in Table II, the degree of adherence relates to adherence at oxidation temperature and ignores the fact that many adherent films have exfoliated on cooling. The thickness of scale on both sides of the specimen is given, since in most cases the thicknesses on opposite

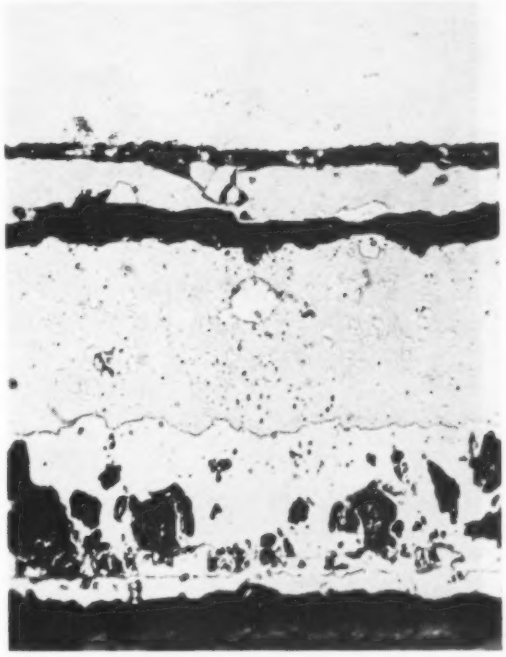


3 *Marker at metal/oxide interface after oxidation of iron at 800°C showing co-operation of film on either side (specimen no.9)* ×40

TABLE III Composition of adherent scales formed on iron

Specimen no.	Temp., °C	Time, h	FeO, %	Fe_3O_4, %	Fe_2O_3, %	Position of marker
1	750	15	95	4	1	At metal/oxide interface
3	750	18	95	4	1	
4	750	19	95	4	1	
5	750	20	95	4	1	
7	750	65	97	2	1	
8	780	24	95	4	1	
6	800	15	95	4	1	
9	800	15	95	4	1	
10	800	16	90	7	3	
11	800	36	95	4	1	
12	830	15	90	9	1	
13	870	18	91	8	1	In wustite layer
14	900	4	90	8	2	At metal/oxide interface
19	950	17	90	8	2	In wustite layer
20	1000	43	80	15	5	
23	900	16	80	16	4	In wustite layer
24	900	16	83	15	2	At metal/oxide interface
25	900	16	83	15	2	

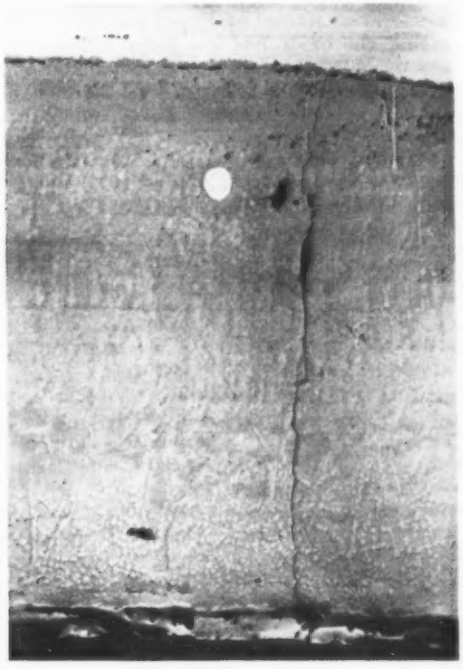
sides of the specimen were not equal. It was quite clear that the effect noted by Dunnington was taking place. In many cases the scale on the whole of one side of the specimen would be of one thickness, and that on the opposite side of a different thickness. In some cases, however, the thick film would change sides as one moved from one end of the section to the other, showing evidence of the co-operation noticed by Dunnington (*see* Fig.3). When exfoliation occurred on one side, the oxidation rate decreased, and so this would become the thin side with a large proportion of the higher oxides. The film on the other side would remain in contact and thicken normally. When the marker happened to be on the adherent side it was found at the metal/oxide interface or near it. When it happened to be on the other side, it was well embedded in the film.



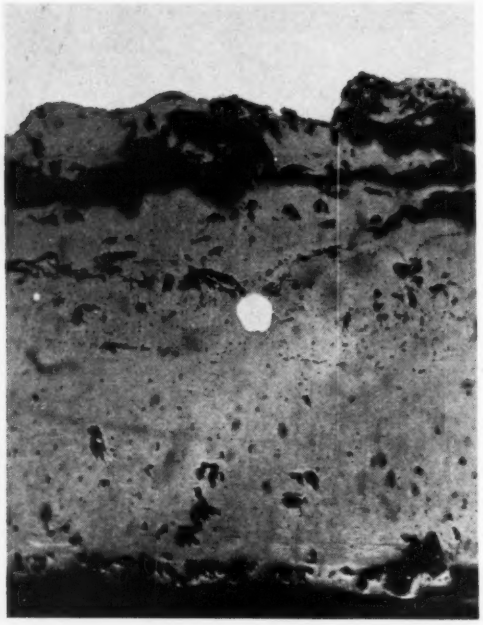
5 *Marker in non-adherent scale after oxidation of iron at 750°C (specimen no.5)* ×200

The composition of the scales on the adherent side was measured microscopically and is given in Table III. The composition of the scales is generally in agreement with the results obtained by Païdassi.[14] It is only

4 *Marker at metal/oxide interface after oxidation of iron at 800°C (specimen no.6)* 100×



6 *Marker in dense adherent film of wüstite after 18 h at 870°C (specimen no.13)* ×100



7 *Marker in Pfeil-type film after oxidation of iron at 950°C (specimen no.19)* ×75

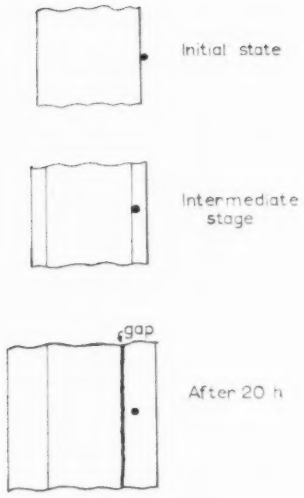
at 900°C and above that there is a significant difference between the two sets of results. Païdassi maintained 95% wüstite in his films up to 1000°C, which may be due to differences in metal purity or thickness.

During the examination of the microsections it was noticed that the rate of oxidation was reduced at the corners of the specimen, so giving rise to the 'waisting' of the specimen noticed by Engell and Wever.[3] It was clear that the oxide had not been adherent at the corners owing to the difficulty of accommodating the large stresses arising in this area with the small degree of plasticity available. The result of the non-adherence was an increase in the proportion of the higher oxides at the corners. The 'waisting' effect was only observed at temperatures below about 900°C. At higher temperatures a rounding of the corners of both the metal and oxide was observed.

The films formed at 750°C tended to be adherent on one side only, and where the marker was on the adherent side, it was found at the metal/oxide interface. When it was situated on the non-adherent side it was to be found in the dense scale which contained a considerable amount of Fe_3O_4 (Fig.5).

Between 780°C and about 830°C the films adhered to opposite sides alternately, the marker remaining at the metal/oxide interface when on the adherent side (Figs.3 and 4). The oxide is dense and so far there is no sign of a Pfeil-type layer. As at 750°C, the non-adherent parts of the film tend to contain a larger proportion of the higher oxides. Elsewhere, the film is predominantly wüstite, with some Fe_3O_4 precipitation on cooling.

Above about 830°C, the films again become non-adherent on one side but the marker is now to be found within the dense oxide film on the adherent side (Fig.6). The non-adherent side contains a great deal of the higher oxides.



8 *Movement of marker during oxidation of iron at 750°C*

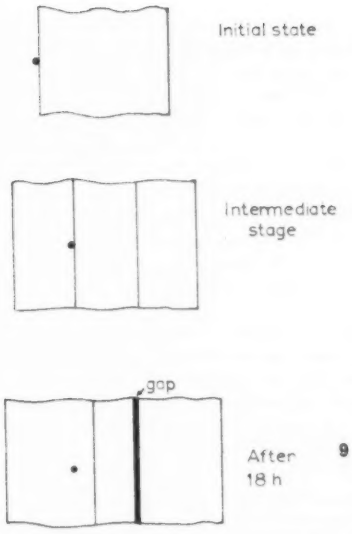
Above about 950°C one side becomes completely non-adherent while the other side reveals a Pfeil-type film with the marker within it (Fig.7).

It is clear that exfoliation is dependent upon oxidation time and specimen thickness, since that oxidized for only 4 h at 900°C has both sides adherent, while the specimen oxidized for 15 h at 830°C has one side non-adherent. The effect of specimen thickness is shown by the difference in adherence of films formed on specimens oxidized for 16 h at 900°C. The films on the thick specimens, 0·36 and 0·37 in. thick, had remained adherent during oxidation, while the film on one side of the 0·18-in. thick specimen had exfoliated. In the case of the thick specimens, the markers were situated on the metal/oxide interface, while on the thin specimen the marker was found within the scale on the non-adherent side.

It is certain, therefore, that at 900°C, 0·36 in. of metal is sufficient to act as a reservoir for vacancies for times up to 16 h. The effect of film thickness is in agreement with recent work by Peters and Engell[15] who found that the adherence of films on iron decreased with increase in film thickness. However, the thickest film investigated by them was about 0·013 in., i.e. well below the general level of film thickness obtaining in this work.

Movement of markers in films on iron

It is now generally accepted that inert markers need not remain at the original interface but may move inwards under the influence of surface tension forces in films having sufficient plasticity. Measurements made on a specimen oxidized at 750°C for 20 h, show that the marker on the non-adherent side had moved inwards 0·004 in., which indicates that the film had sufficient plasticity to make this possible. Figure 8 shows how the process has progressed in this particular case. As the metal/oxide interfaces move towards each other, there comes a time when the metal can no longer absorb the vacancies at a sufficient rate, and these aggregate at the interface causing rupture on one side. After this, diffusion of oxygen and restricted flow of metal ions build up the wüstite round the marker. This, together with the rigidity of the increasing

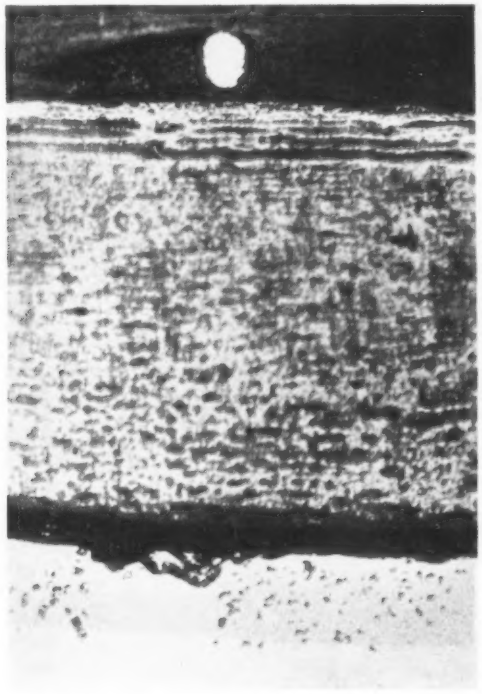


9 *Movement of marker during oxidation of iron at 870°C*

thickness of magnetite, prevent further movement of the marker, which is more or less fixed in the position it had before rupture occurred. Movement on the other interface continues in an inward direction. Figure 5 shows that in this case the marker on the non-adherent side is still in wüstite, that there is little magnetite on the inside of the film and that the Fe_3O_4 precipitated on cooling is now more evenly distributed.

At higher temperatures, as in the case of the specimen oxidized at 870°C (Fig.6), the marker must have moved inwards as much as 0·012 in. before increasing oxygen penetration caused it to be buried in the film. At some stage the film on the opposite side to that shown in Fig.6 became non-adherent and acted as a sink for vacancies. The stages in this process are shown in Fig.9. In this case there is very little porosity near the metal/oxide interface and the thickness of the Fe_3O_4 is still only 8·0% of the total; a figure no greater than at 750°C.

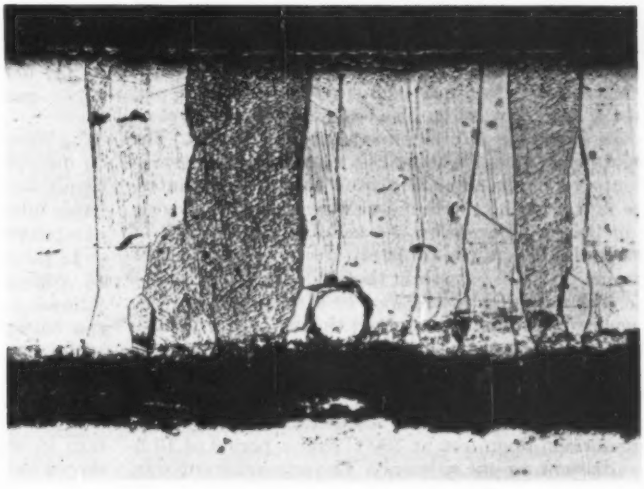
At still higher temperatures, as in the case of the Pfeil-type film shown in Fig.7, the rate of accumulation of vacancies is greater than the rate of their diffusion to the space on the other side of the specimen. Here, oxygen penetration and porosity are present together, but even so, the marker has moved inwards about 0·007 in.



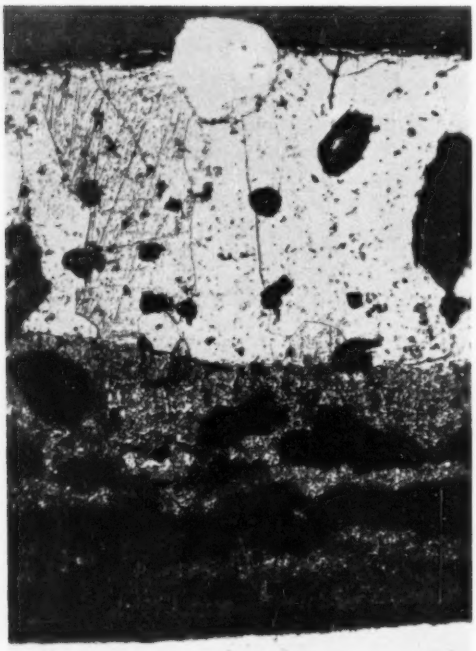
11 *Marker at oxide/air interface after oxidation of titanium at 800°C* ×300

Position of markers in films on non-ferrous metals

Pure copper was oxidized for periods between 2 and 15 h in the temperature range 800–880°C. In all cases the markers were found at the metal/oxide interface. Titanium was oxidized for periods up to 16½ h at 800°C and 2 h at 1000°C and in all cases the markers



10 *Marker at copper/oxide interface after oxidation at 800°C* ×220



12 *Marker at oxide/air interface after oxidation of Cu–1%Al alloy at 880°C* ×200

were on the air/oxide interface. Zirconium was oxidized at 800°C for 17 and 44 h, and the markers were found, like those on titanium, at the air/oxide interface.

The position of the markers on titanium is therefore not in agreement with the recent work by Kinna and Knorr[12] and Hurlen,[13] but does support the conclusions of Davies and Birchenall.[11]

Figure 10 shows the position of a 0·001-in. dia. marker on copper, and Fig.11 shows the marker outside the film on titanium. In the case of both titanium and zirconium the film is porous and laminated, and the metal/oxide interface is irregular. However, the film on zirconium is adherent even after cooling, while that on titanium, although adherent during oxidation, exfoliates on cooling.

The copper–aluminium alloy showed, as expected, a decreased oxidation rate compared with pure copper, but the marker was found to be in the scale layer close to the oxide/air interface, as shown in Fig.12. The structure of the scale shows the usual columnar grains of cuprous oxide extending from the air/oxide interface towards the oxide/metal interface. The region immediately adjacent to the metal was composed of fine equiaxed grains, probably due to the effect of alumina on grain growth in the oxide. Internal oxidation had occurred, giving rise to a subscale of Al_2O_3 particles distributed throughout the metal in a definite band, and along the grain boundaries of the metal.

DISCUSSION

Dunnington's observations adequately explain why films formed upon iron at 750°C over a period of 16 h are adherent on one side only. The non-adherent side does not admit oxygen easily to the base of the film, as the film is still dense and relatively impermeable to oxygen, but there is an increase in the Fe_3O_4 content on this side only, and the marker resides within the wüstite. Between about 780°C and 830°C the film tends to maintain contact alternately on either side.

Above about 850°C the films appear to be more permeable to oxygen and there is a tendency for at least one side to break away and form a film with a large amount of the higher oxides. The film on the adherent side is usually of the Pfeil-type, but in some cases dense films are found with the markers within them.

There is no evidence that the outer layers are having any effect on adherence, as suggested by Juenker. The Pfeil-type film can be adequately explained by the Dunnington mechanism, and no increase in the thickness of the layers of higher oxides occurs simultaneously with the presence of the marker within the film. Indeed, as shown in Table III, it is not until 1000°C is reached that the proportion of Fe_3O_4 shows an increase.

The effect of increasing the specimen thickness is to delay the onset of exfoliation. This is not in agreement with Dunnington, who suggests that increasing the specimen thickness should increase the tendency towards exfoliation, since it reduces the vacancy concentration gradient within the metal. However, if one regards the metal itself as a reservoir for vacancies, increasing thickness would be expected to delay exfoliation.

The apparent movement of the marker into adherent films only occurs at high temperatures after fairly long times, i.e. 18 h at 870°C in the case of material 0·060 in. thick. The films in which this occurred seem to be mainly of the Pfeil-type. These tend to show a porous layer between the marker and the metal interface, but in spite of this porosity a good deal of the film material adheres to the metal surface. Such films are relatively permeable to oxygen, partly because the outward movement of metal ions is restricted by the porosity and partly because oxygen diffuses in more easily via the grain boundaries.

The presence of the marker within the scale is therefore connected with the following factors:

(i) relatively plastic wüstite scale
(ii) inward diffusion of oxygen
(iii) decreasing rate of diffusion of vacancies compared with the rate of their creation.

It is clear that there is sufficient metal/scale contact to maintain outward flow of metal ions, but the tendency for the vacancies to congregate at the metal/oxide interface and form holes is not always effectively compensated by inward oxygen movement.

In the case of copper the effect of 1%Al is sufficient to stiffen the cuprous oxide film and prevent it following-up the retreating metal surface; holes form, the cuprous ion flow is restricted by these and the alumina present, and the marker is now found outside the film.

The difference in the adherence of films on zirconium and titanium probably arises from the deformation in the zirconium metal itself, which has been shown to take place by Hérenguel and others.[16, 17]

SUMMARY AND CONCLUSIONS

The present work has shown that the mechanism put forward by Dunnington *et al.* is essentially correct in the temperature range 750–1000°C on iron of the purity used. Between 750° and 850°C co-operation exists between the two sides of the specimen, the failure of one side to adhere due to vacancies congregating at the metal/oxide interface provides the vacancies arriving at the other side with a sump and so assists the adherence of the oxide.

At about 900°C the rate of creation of vacancies is so rapid that the metal is rapidly saturated and gaps are formed at the interface. Although the film has a high degree of plasticity and can in some cases form dense scale, in many cases it appears to be unable to follow-up the retreating metal surface sufficiently rapidly to prevent a Pfeil-type porous oxide film which is to a certain extent permeable to oxygen. In such cases the marker is found embedded in the film substance.

Experiments made at 900°C show that relatively thick metal specimens delay exfoliation of the film and therefore absorb the vacancies arriving at the metal/oxide interface. Sooner or later, however, the metal becomes saturated and exfoliation occurs on one side. On the adherent side, in all tests made at 900°C the markers were found on the metal/oxide interface. It would appear, therefore, that the vacancy gradient within the metal is not as important as Dunnington suggests. Up to the time of exfoliation the vacancies are probably dispersed evenly throughout the specimen; the metal thickness determining the capacity for absorbing these vacancies.

The addition of 1%Al to copper changes the position of the marker from the metal/oxide interface to the outside of the scale. It is suggested that in this case the presence of Al_2O_3 in the base of the film stiffens the cuprous oxide in this region and prevents it following-up the retreating metal surface.

In the case of titanium and zirconium, the markers were found on the outer surface of a porous oxide film.

ACKNOWLEDGMENT

The authors' thanks are due to the British Iron and Steel Research Association for supplying the Swedish charcoal iron, APC.

REFERENCES

1. L. B. Pfeil: *JISI*, 1929, (I), 501–547.
2. L. B. Pfeil: *ibid.*, 1931, (I), 237–255.
3. H. Engell and F. Wever: *Acta Met.*, 1957, **5,** 695–702.
4. M. H. Davies *et al.*: *Trans. AIME*, 1951, **191,** 889–896.
5. K. Sachs: *Metallurgia*, 1956, **54,** 11.
6. D. W. Juenker *et al.*: *Corrosion*, 1958, **14,** 39.
7. J. D. Mackenzie and C. E. Birchenall: *ibid.*, 1957, **13,** 783–785.
8. R. F. Tylecote: *JISI*, 1960, **196,** 135–141.
9. B. W. Dunnington *et al.*: *Corrosion*, 1952, **8,** 2–13.
10. J. Bardeen *et al.*: *J. Chem. Phys.*, 1946, **14,** 714–721.
11. M. H. Davies and C. E. Birchenall: *Trans. AIME*, 1951, **191,** 877–880.
12. W. Kinna and W. Knorr: *Zeit. Met.*, 1956, **47,** 594–598.
13. T. Hurlen: *Acta Chem. Scand.*, 1959, **13,** 695–704.
14. J. Païdassi: *Acta Met.*, 1958, **6,** 184–194.
15. K. F. Peters and H. J. Engell: *Arch. Eisenhüt.*, 1959, **30,** 275–282.
16. P. Hérenguel *et al.*: *Compt. Rend.*, 1956, **243,** 2060–2063.
17. C. A. Phalnikar and W. M. Baldwin: *Proc. ASTM*, 1951, **51,** 1038–1059.

POWDER METALLURGY JOINT GROUP

The Iron and Steel Institute
The Institute of Metals

FORTHCOMING MEETINGS OF THE GROUP

1960 Winter Meeting, 15 and 16 December 1960

The next meeting of the Powder Metallurgy Joint Group will be held at Church House, Great Smith Street, London SW1, on Thursday and Friday, 15 and 16 December 1960. Details of the programme were given on p.352 of the *Journal* for November.

1961 Spring Meeting

The Spring Meeting of the Group will be held at the Royal Commonwealth Society, Northumberland Avenue, London WC2, on Monday and Tuesday, 17 and 18 April 1961, when there will be a discussion on '*The appraisal of powders for pressing and sintering*'. The afternoon of Monday, 17 April, will be devoted to a discussion of three specially invited review papers dealing with '*Techniques for the evaluation of powders*'. The whole of Tuesday, 18 April, will be occupied with a discussion on '*The relationship between properties of powders and their pressing and sintering behaviour*'.

The Powder Metallurgy Joint Committee invites the submission of papers describing original, unpublished work for publication and discussion at meetings. Offers of such papers, accompanied if possible by brief synopses, should be sent to the Secretary to the Group, 17 Belgrave Square, London SW1.

1961 Winter Meeting

The principal theme for discussion will be '*Sintered materials for high-temperature service*'.

Offers of papers describing original, unpublished work for this meeting are invited.

1962 Spring Meeting

The principal subject for discussion will be '*Disperse-phase-hardened systems*'.

Offers of papers describing original, unpublished work are invited.

Discussion on steelmaking in electric-arc furnaces

ANNUAL GENERAL MEETING 1960

A report of the Annual General Meeting was given in the August 1960 issue of the Journal. *The main technical sessions were devoted to a symposium on wide strip production: discussions from these sessions will be published in a Special Report early in 1961. A discussion from the session on steelmaking in electric-arc furnaces is given below.*

This discussion was based on the paper **'The new electric melting shop of Steel, Peech and Tozer'**, by *R. S. Howes* and *A. Jackson* (*JISI*, 1960, **195**, May, 95–99). The paper was presented by Mr Jackson and Mr J. D. Wright, who was deputizing for Mr Horves, Mr W. Barr, O.B.E., was in the chair.

Mr **P. M. Thomas** (William Beardmore and Co. Ltd): I congratulate the authors on a very interesting paper. The large arc furnace is just coming to the forefront in the UK, and there is still a very great deal to learn and discuss on this equipment.

At Parkhead we have been operating a furnace for some time now on stainless steels, alloy steels, and fairly large forging ingots. The very high production rate in these large arc furnaces is most striking. Here we are talking of a tap-to-tap time of 3 h 20 min, and it would be interesting if the authors could tell us the times for charging, melting, refining, tapping and fettling, changing electrodes, and particularly, what allowance they have made for delays. We still lack experience with this equipment and find that numerous small delays do occur; minor electrical and mechanical matters have to be attended to, as well as broken water pipes, broken carbons, etc. While this does not seriously affect our type of production, the time lost in a cycle time of 3 h 20 min might be considerable. Roof changing, and in particular relining, cause more serious delays. I would be interested to hear from the authors what sort of roof life and lining life they expect to get, and how often they expect to reline the furnace. The shell of our furnace can be removed and replaced by another shell with a lining on. We do not in fact do this, but I wonder if the authors considered it.

We are particularly interested in the serious problem of the hot spot by no.2 electrode. I understand that on GWB furnaces there is now an electrical device which corrects this peculiar arc factor and is reputed to improve this hot spot on the lining. Nearly all arc furnace users in the UK have this trouble, and the bigger the furnace, the higher the power, the worse is the problem. I should like to know what practical experience there is of this device, and whether it could perhaps be incorporated in existing furnaces.

I have mentioned the question of broken carbons, and I wonder whether the authors have considered any special device for dealing with these. On a small furnace the handling of a 12-in. carbon is a relatively simple matter, but dealing with a 20-in. carbon, particularly when broken quite early in the melt, embedded in scrap, and at high temperatures, can be very difficult, and clearing can take a long time. We are still experimenting with a more effective handling gear.

On electricity supplies, I should like to make three points. Have special design precautions been taken in the furnace transformer, because both Samuel Fox and ourselves have had serious transformer breakdowns? I believe that there was serious trouble in this respect in one of the Continental furnaces. When I discussed this with transformer manufacturers about a year ago, it was apparent that they still had much to learn about the switching surges to which these transformers are subjected fairly frequently compared with normal grip transformers. The transformers in this project, of course, are more than twice as large as ours.

I notice from Fig.3 of the paper that provision is made for possible reactors; why 'possible'? We have capacitors on all our furnaces and run at a power factor of about 95% overall as opposed to 80–82% without. We think that these are almost essential and pay for their capital cost within 12–14 months.

Little has been said about electricity tariffs, but when using a large quantity of electricity, these are obviously of vital importance, and there are a lot of arc furnace users who are seriously concerned about the problem of getting a suitable tariff for arc furnaces, so that it would be interesting and possibly helpful to the whole industry if we could be told something about this.

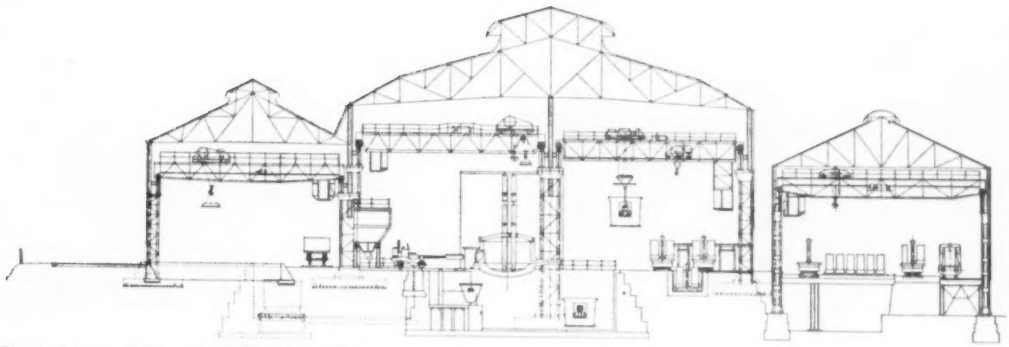
There are two points I should like to make on raw materials. What arrangements, apart from basket charging, have been made for mechanical charging, i.e. the alloys, the slag-making materials, and so on? Are there any floor chargers, overhead chargers, or fully mobile chargers, and, if so, how many? It would appear from Fig.2 that there might be considerable difficulty in getting a charger to serve several furnaces, because with the scrap basket in position on the stage there is very little clearance between the slag bucket and the transformer houses.

There appears to be provision made for very substantial drying equipment for alloys. Do the authors really consider this necessary for the types of steel they are going to produce? I feel there is still considerable doubt as to the value of drying alloys, even when making high-grade steels. I believe that Bethlehem are the only people who have produced figures to show that it is really of value. As it appears that the majority of hydrogen pickup in a furnace is during refining, under a reducing slag, I wonder why so much area has been laid aside for this drying equipment.

On fume extraction the authors have not come to any final conclusions. Our furnace was installed before the Clean Air Act became law, but we anticipated it and decided to extract fumes through hoods over the furnace and the doors. This method complicates the maintenance of ancillary gear not above the roof, but within the hood, owing to high temperature concentration.

However, we were doubtful about the alternative method of direct extraction from the furnace body, as in making high-grade steels it is very desirable to maintain a positive pressure in the furnace and not draw damp air into it. If this were used it might require delicate automatic pressure regulating equipment which would be difficult to maintain.

Finally, I should like to ask whether anything is being done about noise. Even one furnace working on 18 kVA makes a great noise when it starts breaking down, and there is considerable vibration. I can imagine what the noise might be with six furnaces breaking down at 40 kVA, and I wonder whether any thought has been given to the acoustic design of the building.



A *Vertical cross-section of electric melting plant*

Mr **J. D. Wright** (in reply): The first point raised by Mr Thomas was the output rate. The breakdown of the 3 h 20 min time which we hope to achieve on low carbon rimming is as follows: charging and melting, 2 h (assuming one back charge); refining, 1 h; fettling, 20 min. We do not quite see why we should need 1 h to refine, assuming a 30 or 40 point boil and an oxygen consumption of about 20 ft³/min ton. I would think that a 15–20 min blow at most ought to remove the carbon. Any extra time should be added to the charging or melting period; but a furnace of that size should melt 1 ton/min. No allowance is made for the minor delays that Mr Thomas mentioned. There will be some delays, of course. Electrode changing will be off the furnace because of the difficulty in making a reasonable joint on the furnace itself. There will thus be electrode changing, as well as mechanical and electrode delays. These are not included in the 3 h 20 min.

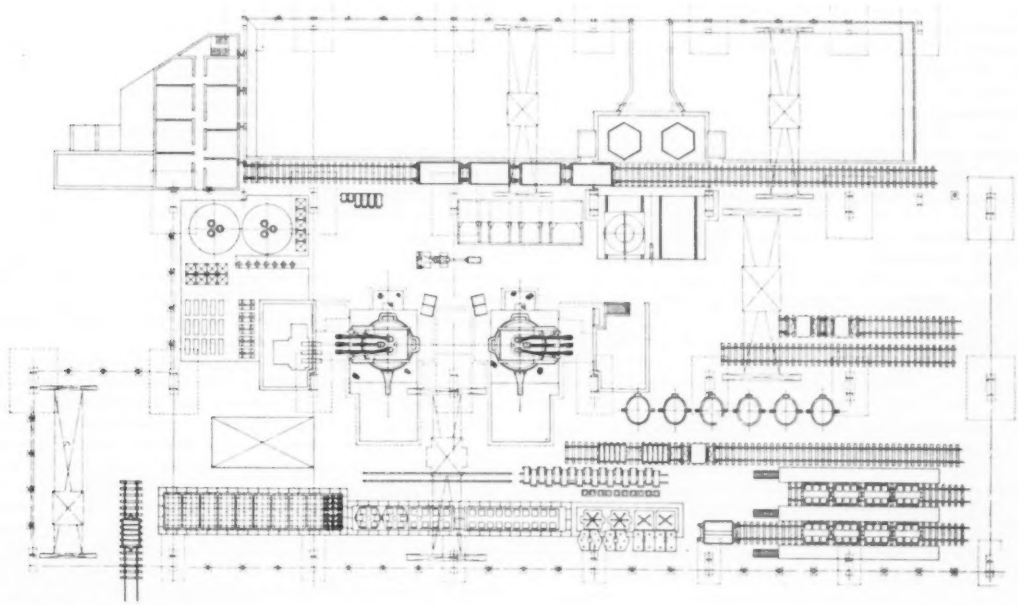
I do not know what the lining life will be. I think that Mr Thomas has more experience of this than we have in large arc furnaces. We hope to achieve considerable mechanization in furnace relining, e.g. by the use of dismantling irons in the brickwork, placing a mild steel tray at the bottom of the furnace and heaving the whole side wall in, and perhaps water cooling of the tray to give reasonable bricking conditions. By extensive mechanization we hope to keep the down-time to a minimum. Furnace availability is put at 94%.

As regards the hot spot, it is true that on the two furnaces that we have ordered there is an electrical device with the fourth electrode arm, which I believe evens out the reactance of the three phases and consequently takes away the hot spot from the back electrode. I hope that it will not put it anywhere else! I think this is one way of dealing with the hot spot that has been proved in practice, although I cannot give any details.

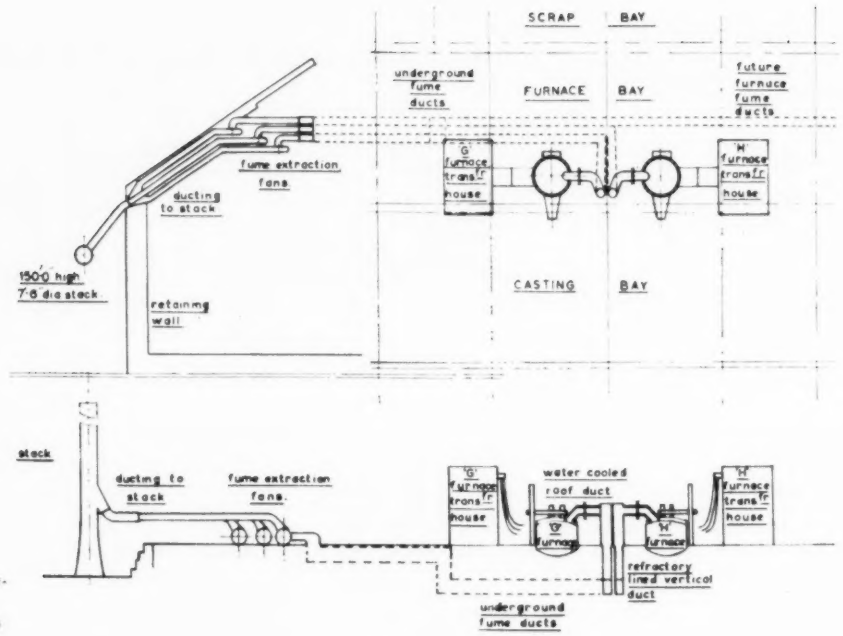
The question of broken electrodes is again something about which Mr Thomas knows more than we do. On our existing 5-ton furnace it is easy, but I can appreciate the problems in a big furnace, and undoubtedly it will have to be considered very carefully.

On the matter of the capacitors, apparently this is not only tied up with the power factor, but with cyclic voltage fluctuations, etc., and I believe that we have to keep those down to 0·5% on the 275 kV side. The CEGB has agreed to let us put these furnaces in without a capacitor because it is guaranteed that we can meet this stipulation. It depends upon what happens on those furnaces whether we shall have to fit capacitors to the other furnaces.

Negotiations are in progress at the moment on the tariff.



B *Plan of electric melting plant*



C Top: *Plan of fume extraction.* Bottom: *Vertical section of fume extraction*

I have no figures, but a two-part tariff is being negotiated. There will be a charge for maximum demand in megawatts, a unit charge with a coal variation clause, and presumably some sort of minimum power factor requirement.

Turning to charging, we will have a floor charger and there will just be room for the charger to get through with the basket in the in-position. Normally the basket is not left in that position, but is left retracted if one does not want to pick it up on a crane. In addition, there will be reinforced sections of the stage where one can take the basket off the transfer car and put it down on the standing, which will ease the congestion; but it will be possible to get a floor charger through.

On the question of alloy drying, on what few alloy steels we do make, traditionally we have dried our alloys. Whether it does any good or not, I do not know; if it does, we take advantage of it. It is only necessary, of course, in the alloy grades and high-manganese steels, which in big sections, at any rate, are susceptible to hairline cracking. However, vacuum casting obviates the need for alloy-drying facilities.

On fume extraction I can add nothing to what has already been said; the situation just has not been finalized yet, and finally, as regards the noise, you will notice from Fig.1 that the melting shop office is right at the other side!

Dr **W. S. Walker** (Round Oak Steel Works Ltd): It will be interesting to listen in two years' time, or thereabouts, to a description of what has actually happened in the shop at Steel, Peech and Tozer, and to see all this planning coming to fruition.

Like Steel, Peech and Tozer, though on a much smaller scale, in our cold metal shop at Round Oak in 1957 we were faced with the problem of increasing our steel-melting capacity, and after quite intensive research, both in the UK, abroad, and through the literature, we decided to put in large electric melting furnaces rather than extend the Siemens melting shop. The shop has already been described elsewhere.*

Figure *A* shows a section through the shop, which was built on an old tip, a very awkward site; the existing building (an old melting shop) was used as a stripper bay and mould stock bay. A scrap bay with a lateral transfer bucket into the shop was built. We decided on furnaces set on the floor, and arranged for slag disposal in a pit on one side of the furnace Probably the Steel, Peech and Tozer scheme is somewhat better, but nothing else was possible in our case. Figure *B* shows a plan of the shop with the scrap handling bay, the furnace bay, and the casting bay.

We decided to extract the fume through the roof (Fig.*C*). I believe that this is the best way, but we have by no means solved all our problems. We draw off the fume through a 30-in. dia. hole in the roof and down into what amounts to a cooling box. Through this box the fume is taken by underground ducting via fans to an existing stack. When we have solved our various problems it is proposed to put in cleaning equipment: I do not know what sort of cleaning equipment we shall use, and I do not think anybody can say just what is the best type at the present time.

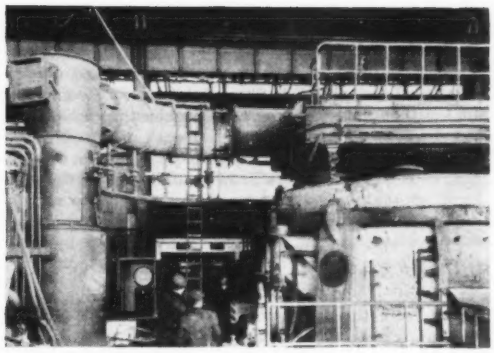
There was one snag that we came up against. By putting water in the vertical downtake near the furnace to try to cool the exhaust gases, dissociation occurred. This caused minor explosions in the underground duct. It is necessary therefore to cool the fume speedily and effectively, and we are now redesigning part of the cooling box to permit the use of larger quantities of water.

Figure *D* shows the fume extraction duct from the roof. There is an elbow attached to the roof structure. To allow the roof to swing there is a gap between this and the horizontal water-cooled duct. This system works admirably on single-slag steels, but when working the furnace with a reducing slag to date we have had some difficulty. We have found that the manganese loss is higher when working the furnace with fume extraction than without fume extraction.

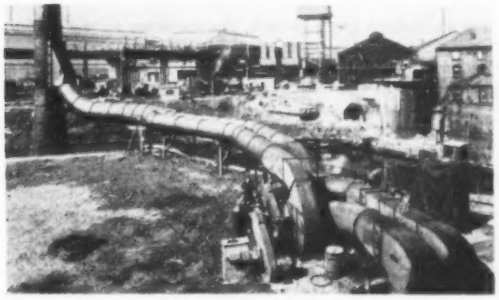
Figure *E* shows the extraction system from the underground duct, and we have put in simple slide valves to admit sufficient cold air to keep the fans at a satisfactory working temperature.

The authors said that they are going to have two-bucket charging. We have found that with Midland scrap this is not always possible, and in fact we have laid down a policy that the electric furnaces act as beneficiators of scrap to our Siemens shop, although this delays furnace operation. We also find that the use of a lot of turnings also delays the furnace considerably, if the turnings comprise over 50% of the weighed charge. The turnings are sometimes covered in sulphonated oils and there is sulphur pick-up inside the furnace. Incidentally, when using turnings a lower ingot yield is obtained.

* *Iron Coal Trades Rev.*, 1960, **111**, 917–924.



D *Fume extraction duct from roof*



E *Extracting system from underground duct*

We have actually had a 70-ton heat out in 3 h 50 min, so I think that the projected figures are quite reasonable. We have averaged 530–540 kW/ton on certain heats, but again, with very poor scrap, these consumptions may reach 630 and 650 kW/ton. I do not think that we have yet learned to operate the furnaces quite correctly on some of these charges, but this should improve with practice.

On the question of hot spots, I believe that the system that the authors are adopting is to have a dummy arm alongside no.2 electrode to balance out the reactance. Electrically this is sound, but there are certain disadvantages in that one has thin insulation carrying the full furnace voltage at high temperatures, and this may cause trouble. We are thinking of introducing into this circuit a reactance of a type with a choke and a floating core.

One of the things that we have come up against in handling our poor scrap is lumps of concrete and non-conductors generally, and this gives rise to electrode breakages. We have certain ideas how to overcome this other than by better scrap selection.

On oxygen blowing, I would agree with the figures that the authors have quoted, but we have had some quite successful experiments with oxygen–steam mixtures, and I think that is something which is worth bearing in mind.

Mr **T. H. Harris** (Round Oak Steel Works Ltd): Mr Thomas mentioned the problem of removing broken electrodes from the furnace. We use patent tongs which are held open by a catch device and released when brought into contact with the electrode. We find them very effective.

This most interesting paper raises in my mind a number of questions and I think I can do no better than list them:

1. If the furnaces were going into a new building would they have been put at ground level or on a stage? At Round Oak the furnaces were installed at ground level for reasons of economy but we do lose some storage space. This is not as much as might appear, as a considerable amount of equipment has to be accommodated underneath the stage.

2. Is there any provision for receiving scrap and raw materials by road? In the Midland area we receive over 60% of our scrap supplies by road and this appears to be a growing trend.

3. Is any special mechanical equipment envisaged for handling the slag at the lower level? We use 10-ton slag bowls which are positioned in slag holes fitted with removable cover plates. The bowls are lifted by the 75-ton charging crane and placed in carriages for tipping. With poorer grades of scrap and the consequent increase in slag volume carried, time is sometimes lost by slag bowl changes being necessary during a heat. Any means of dealing with the slag at the lower level would be an advantage.

4. Why nine basket filling stations? We find that a 15-ton magnet crane can easily load at 40 to 50 tons per hour and one crane and one basket filling station per furnace should be sufficient. By reducing the number of magnet cranes and filling stations to six about £50000 would be saved in capital cost and £5000–£6000 per year in crane-drivers' and weighmen's wages.

5. Why a 24-ft shell for 110 tons? It is generally agreed that the most efficient way of working an electric furnace is to overcharge it and to get the furnace full of scrap so that full advantage can be taken of high voltages; 40% of the scrap supply will be fairly heavy and undercharging might lead to excessive side wall wear. On the question of side wall wear, one hot spot has been mentioned but there are, in fact, two, and we find panels of electro-cast blocks are essential in these areas to reduce localized erosion. To aid in wrecking a lining, steel strips are built in at the back of the lining. These are not always fully effective as, with a lining of metal cased bricks, the strips sometimes pull out before the wall is broken down.

A further question (rather outside the scope of the paper) is, why use German furnaces when the main features of the design, e.g. 'American bridge' principle of roof slewing, rotating hearth, and hydraulic controls are available in the UK?

Mr **J. D. Wright:** As regards bucket charging, we hope to get away with two charges, but possibly, if we get a lot of light scrap, we may have to go to three buckets, and that will lengthen the melting time.

With regard to the four electrode arms, I cannot go into this matter very deeply, but I believe that the system is to use water-cooled cables with them.

On the question of poor conductivity scrap, lumps of concrete and local aggregations of lime, the furnaces are fitted with body rotation. We can alter the position where the electrodes strike the charge. We hope that this will cope with the problem of the poor conductivity charge, which is a very real one.

In reply to the question about whether in a new building we would put the furnaces on ground level or a stage, I should have thought that if one were to put the furnaces on a stage, one would have to put a great deal on the roof work of the shop, which might add to the expense. I think that it would be better, if possible, to keep the furnaces at floor level.

As to the reception of scrap by road, it may well be that we shall receive a large amount of scrap by road, and in fact we do receive some by road now. Possibly the amounts will go up considerably, but we are hoping to cope with the reception of a large proportion of our scrap by road transport.

Slag handling has not yet been finalized. One scheme is to use road transport to remove the slag.

The diagram shows nine basket transfers, but we have now finally decided on seven basket transfers, with five basket standing positions on the stage itself.

On the question of a 24-ft dia. shell for a 110-ton tapping, I entirely agree that it is a large furnace for tapping 110 tons. With single slag steelmaking I should have thought that a shallow bath was a very useful thing to have in that one relies on all the refining in the single slag stage being done by slag/metal contact, and it speeds up the refining.

One way of increasing a shop's output ratio as a result of

putting in electric furnaces is to charge more in the existing furnaces.

The two hot spots are associated with the leading and lagging phases in the electrodes. It is quite possible that we may have to use fused chrome–magnesite bricks.

With regard to furnace design and hydraulics *v.* electrics, this was all considered extremely carefully when our decision was made at the time.

Monsieur **L. G. Husson** (IRSID): If I clearly understood the meaning of the transformation carried out by United Steels, the replacement of their OH furnaces in Sheffield with electric-arc furnaces was mainly justified by the wish to supply these furnaces entirely with scrap, to the exclusion of any solid or liquid iron input, in order to keep all the iron available for their plant at Appleby-Frodingham.

A complete study of the problem has led them to the conclusion that, in this special case, the suggested formula gave the lowest cost for both plants. In France, a large steelplant making special steels has also reported, in recent years, an economic advantage in substituting big electric-arc furnaces for old OH furnaces.

I do not intend to discuss these conclusions based on very long studies, since I do not know all the factors. But I should like to point out, however, that from the experience IRSID has gained during recent years, it would seem unwise to generalize on them.

First of all, from the point of view of the choice of raw materials, it is still commonly admitted that the electric-arc furnace, in spite of its flexibility, does not lend itself as well as the OH furnace to the refining of high proportions of iron. But, conversely, the OH furnace is considered unable to be charged exclusively with scrap and coal or coke. However, I applied this formula myself a quarter of a century ago and the difficulties encountered at that time have since nearly disappeared. The reason for this is that the melting power of the present furnaces has been greatly increased.

In fact, I recently visited a Belgian steelplant which uses in its OH furnaces, at least for the refining of mild steels, only scrap, coal, and manganese ore. A given proportion of silica required for the formation of slag is supplied by silicon sheet scrap, which could be occasionally replaced with a little ferro-silicon.

As for thermal efficiency, the practical application of the data obtained from the work carried out by the International Flame Research Foundation at IJmuiden has allowed us to improve it considerably in the case of furnaces operating with solid input. This is, as you know, the common practice in France. We consider now that, even without using oxygen, a well-built and well-operated furnace supplied with an entirely solid charge of 20 tons/100 ft², fed with 1 500 000 Btu/h and per 10 ft² of hearth area and with a momentum to the burner of 1·1 lb/10⁶ Btu h, can easily produce 6 250 lb of steel/h and per 100 ft² of hearth area. These figures are from tap-to-tap with fettling time included and without excessive lining wear. All this is essentially a matter of draught and of power of the air-blowing fans.

In these circumstances, fuel consumption must not exceed 4 500 000 Btu/ton, even for small 40–70-ton furnaces. This consumption can decrease below these figures for larger furnaces or for those for which the rate would be increased by using oxygen. The decrease can be made more significant when there is an important liquid input.

This corresponds to a total calorific yield of about 35%, which is able to reach at least 45% during melting. We hope that these results will be again improved in the near future owing to a better design of the regenerators, a question which is of great interest to steelmakers in the UK (I think especially to the checker-works of Shotton with horizontal chimneys), in the USA, and in France.

Of course, I do not claim at all that this ensures, in every case, an economic advantage for the OH furnace over the electric-arc furnace, but I should like to say that the comparison must be established from such data.

Mr **T. Dennison** (Guest Keen Iron and Steel Co. Ltd): I wonder whether the authors could tell us why they have decided to put new electric-arc furnaces in a building designed and used for OH practice. I am sure that there must be very compelling reasons for their furnace layout. I would appreciate even a rough indication of how the capital cost of the proposed development would compare with the expenditure on a similar installation on a green-field site; and secondly, would they care to express an opinion on how far they have had to sacrifice ideal layout to take best advantage of existing buildings and facilities?

Mr **Wright:** I cannot give the relative cost of the present scheme compared with what it would cost on a green-field site. Apart from the cost saving of putting the electric-arc furnaces in an existing building, the present shop is in the optimum position for feeding ingots to the cogging mill. The question of a green-field site was gone into in the early stages of the scheme.

Dr **J. H. Chesters** (The United Steel Companies Ltd): Any refractory manufacturer present here today must have been somewhat alarmed by Table I of the paper, and in particular by the drop from 82·7 to 20·5 lb of refractory material resulting from the change to arc furnaces from OH furnaces. The amount of basic material required is relatively constant, but the silica has dropped from 44·8 to 10·0 lb/ton and the firebrick from 24·6 lb to nil. In yesterday's discussions reference was made to the short life obtained on LD or Kaldo converters. It is true that these wear out in two or three days compared with several months for an OH furnace but it is equally true that their consumption of refractories is from the standpoint of the brickmaker 'shockingly low'.

These radical changes in demand for refractories led me to do some crystal gazing and I would like to hand on the results for what they are worth. Taking 1957 as a relatively stable year, we find that OH furnaces produced 90% of the steel in the UK, the other 10% being equally divided between pneumatic and electric processes. Looking ahead to, say, 1967, it would not be surprising if the proportions had changed to 60% OH, 30% pneumatic, and 10% electric. Of the 60% OH, two-thirds might be made in existing furnaces and the other one-third in special furnaces, such as the Ajax.

Knowing the approximate consumption of refractories for these different processes, and assuming an increase in production from 22 to 30 m. tons, I have tried to calculate the probable changes in demand for refractories used in the actual steelmaking processes as distinct from ironmaking, casting-pit, and reheating furnaces. The answers suggest that whereas basic brick demand for steelmaking may increase by as much as 65%, that for silica and fireclay for the same purpose may fall by as much as 30%. I would stress once again that these are steelmaking figures and in iron- and steelworks the bulk of fireclay refractories are not used in the OH furnace. Even so the results are sufficiently dramatic to warrant closer consideration, indicating as they do a substantial change in the amounts of refractories likely to be required.

Mr **M. D. J. Brisby** (W. S. Atkins and Partners): I think that the capital cost of an OH shop developed on a green-field site is in the region of £13 to £16 per annual ton of ingot. I would suggest that the capital cost of a completely new electric-arc shop is £8 to £10 per annual ton of product and that an LD shop could be built for about the same cost. It must be remembered in estimating the capital cost of a melting shop, that the level of productivity is all important. In a well-designed shop, the additional capital cost involved in producing greater tonnage is frequently quite small.

From what we have heard of the Steel, Peech and Tozer shop where they are making use of existing structures and services I would suggest that the capital cost might be something less than £8 per annual ingot ton.

Mr **A. Jackson** (in reply): Monsieur Husson's point is that a good OH furnace could compete favourably with a good electric furnace. We have considered that point. If the pig iron

charge in the electric furnace is increased from 100% scrap, the ingot cost rises and quickly reaches that of the cold-charged OH furnace, especially if the iron is phosphoric as is ours. If we had used the traditional OH mixture in the proposed electric furnaces, the financial return would not have been sufficient to service the capital cost of the changeover.

Mr **Wright:** As regards Mr Thomas's comments on output rate, I should add that we hope to achieve 3 h 20 min, but if we average 4 h we shall get the projected shop tonnage.

As regards the fourth electrode, we have evidence that it does diminish one hot spot, but obviously the other is still present, so that the problem of non-uniform lining attack is not entirely resolved.

Dr **Walker:** The Round Oak shop cost about £6 2*s* per annual ingot ton in capital.

Mr **D. F. Campbell:** Much has been said about the economics but little about the technical details of the plant itself, and I very much hope that these will follow.

One question that has always been worrying electric furnace operators in the UK has been the unrealistic price of scrap. Of course, that has largely been in the hands of the Iron and Steel Federation, and at one time in the UK it was about half the price of scrap at IJmuiden, which seems quite wrong. Scrap prices have influenced steel makers very much in adopting electric furnaces in the past. In this particular case, The United Steel Companies have very cleverly arranged things so that it will be purely a matter of internal bookkeeping what the scrap is going to cost when it gets to Templeborough. Consequently, they are independent of the scrap market, which makes it much easier to work out the economics of the scheme.

I think that this installation will be of great interest from the strategic point of view. It is of immense value to have in the country a works where one can make almost any quality of steel. It should not be forgotten that in the past the electric furnace saved the situation when war conditions cut off the supplies of steel from Sweden. I am afraid it was rather disastrous for the importers of Swedish Bessemer steel and Swedish raw materials when the Sheffield steel trade turned over to the use of electric furnaces; but I cannot forget the panic that occurred during the first world war when the supplies of Scandinavian raw materials for making crucible steel, ferroalloys, and other products were cut off, and the electric furnaces were put up extremely rapidly. From that point of view, I think that this magnificent plant which is to be built is really of considerable strategic value.

There is one other point I should like to make. The question of making steel at Templeborough was discussed in a paper at The Iron and Steel Institute exactly 50 years ago, and at that time the late Mr E. F. Saniter was one of the very few people who supported the possibility of making low-sulphur and -phosphorus steel in the UK with electric furnaces. It is very interesting that these proposals were discussed long ago when very few people knew what electric furnaces would do in the future. That paper was based on the experience of a French engineer, Paul Héroult, and now virtually every maker of steel furnaces throughout the world is using the combination of three vertical electrodes and a solid hearth put forward by that great but little-known French engineer. This was described in that early paper as the best of several alternative furnace designs and is now universally accepted.

One other thing to be borne in mind is that in the UK engineers have to deal with most difficult sites and very complex traffic problems. At Templeborough the site is narrow, with the River Don on one side and a main trunk road on the other, at Parkhead the furnaces are in the middle of Glasgow, and two other electric furnace shops are built on steelworks dumps at the Round Oak and Brymbo works. These sites are very difficult from an engineering point of view. With the intensive output of an electric furnace, which is going to produce more tons in half the space compared with an OH plant, the traffic problems become most critical. It is a complicated matter to get the raw materials to the right place and the ingots cast properly and rapidly removed without any traffic congestion.

It is to be hoped that the authors will soon write another paper giving more information about the engineering of this remarkable project.

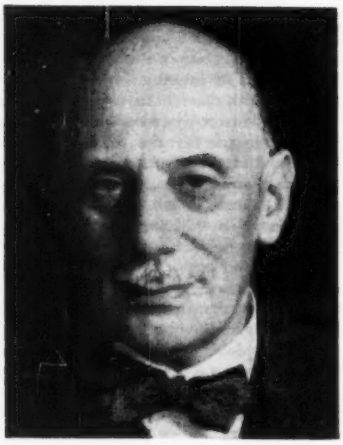
Abstract and Book Title Index Card Service

In order to make abstracts available to users more quickly and in a form more suitable for indexing than the printed Abstracts section of the *Journal*, The Iron and Steel Institute inaugurated an Abstract and Book Title Index Card Service from the beginning of 1960. During the year the number of abstracts printed increased by more than 40% over 1959. The service consists of pre-publication copies of all abstracts and titles of new books on 5 in. × 3 in. library cards with Universal Decimal Classification numbers. Orders for the first year's cards have been received from all over the world. The value of the cards in building up a stock of information will grow with each year of operation, and arrangements have been worked out for helping subscribers taking only one set of cards to prepare bibliographies and list of references. Subscribers receive cards fortnightly, arranged and packed in alphabetical order of authors' names.

Full particulars and details of subscription rates may be obtained on application to the Secretary.

OBITUARY

Sir Charles Bruce-Gardner, Bt.



Sir Charles Bruce-Gardner, Bt., Past-President of The Iron and Steel Institute, died at his home in Berkshire on 1 October. Sir Charles was born in London and educated at St Dunstan's College and at Battersea Technical College, afterwards serving his mechanical engineering apprenticeship at the Westinghouse Company's works at Trafford Park, Manchester. On completion of his apprenticeship, Sir Charles joined John Summers and Sons, Shotton, as assistant to the steelworks manager and rolling mill manager, afterwards succeeding to the position. Later he became assistant works manager and then works manager, and was elected to the board in 1913.

From 1929 to 1930 Sir Charles was chairman of the Iron and Steel Industrial Research Council and a member of the advisory committee of the department of Overseas Trade. In 1930 he joined the Bank of England to become industrial adviser to the governors, and was also appointed managing director of the Bankers' Industrial Development Company Ltd, and of The Securities Management Trust Ltd, the Bank of England company. In 1936 and 1937 he was chairman of the Iron and Steel Exchange.

In December 1937, at the request of the Government, Sir Charles left the Bank of England to assist in the Government's air re-armament programme, and was appointed independent chairman of the Society of British Aircraft Constructors. During the Second World War he served on many Government Committees and in a number of executive positions.

Towards the end of the war Sir Charles was appointed by the President of the Board of Trade to the position of Chief Executive for Industrial Reconversion, to deal with the industrial problems arising from the changeover from war to peacetime conditions. At the completion of this work he returned to the steel industry. He became chairman of John Lysaghts, and was also a director of the Steel Company of Wales Ltd.

Sir Charles joined The Iron and Steel Institute in 1910 and was elected a Member of Council in 1950. He was President in 1955–56.

Sir Charles leaves a widow, two sons, and a daughter. His elder son, Douglas Bruce-Gardner, has succeeded to the baronetcy.

Address by Mr Richard F. Summers at the Memorial Service to Sir Charles Bruce-Gardner, All Saints Church, Langham Place, London, on 19 October 1960

We have come here to this Church this morning to pay tribute to the memory of Sir Charles Bruce-Gardner. Many of us have come as close personal friends, others as admirers of a successful man of commerce who had occupied with distinction many important posts.

I was naturally very touched when I was asked by his family if I would say a few words about him today. In accepting I did so with some trepidation lest I might fail to do full justice to the occasion. I like to think that I had been asked because I had known Sir Charles ('Bruce' as he always was to me) for more than 50 years, and because he had been so intimately connected with my family and our Company.

I first remember him when I was a small boy and he came to work for John Summers and Sons; that would have been, I think, in 1907. He very quickly made a name for himself, and in spite of the disparity in their ages a firm and lasting friendship grew up between him and my father, who held him in the highest regard, and I know that Bruce always felt that my father played an important part in starting him off on his successful career. He stayed with us until 1930, when at the request of the then Governor of the Bank of England he went to be his industrial adviser, at a time when industry was in the throes of one of the greatest depressions in history and the Bank was anxious to lend a helping hand.

In the late thirties, when the clouds of war were gathering fast and the weakness of our air defences was at last fully realized, Sir Charles was called in to take a hand in speeding up aircraft production. When war broke out he placed himself and his very considerable technical and industrial experience unreservedly at the disposal of the Government, and his services were used in many vital spheres. It is fitting that these services received their just reward.

I have always felt that he looked upon these activities as a duty and that his heart was, and always had been, in steel, and therefore it was not surprising that when the national danger was over, as soon as he could, he returned to the industry to which he felt he really belonged. His many friends in that industry were delighted to welcome him back and to see him play an important part in the reconstruction and expansion that has taken place since the war.

He led a full and industrious life, and without doubt a very happy one; he had so many interests, such energy and enthusiasm. I always looked forward to meeting him and talking about steel and fast motor cars, our common interests. His affection and consideration for his wife and his family set an example that all would be well advised to follow. Now his labours are over; he has left the strife and turmoil of this troubled world and gone we believe to a happier land. He has, however, left us with our memories, memories of a keen sense of humour and a ready wit, memories of a kind and generous heart, a happy smile, and that so typical gesture, a friendly wave of the hand in farewell.

E. G. Grace

Eugene Gifford Grace, one of the most distinguished figures in the US steel industry, died in Pennsylvania on 25 July. Mr Grace attended Lehigh University and graduated with a degree in electrical engineering in 1899. He joined the Bethlehem Steel Company in the same year, as an electric crane driver, but later transferred to the steelmaking section. Here he showed the outstanding drive and ability which became characteristic of him throughout his life. After the reorganization of the Bethlehem Steel Company in 1913 Mr Grace was made president, and in 1916 he became president and chairman of the board of the Bethlehem Steel Corporation. Under his direction the Corporation was a major supplier of steel for American armaments in 1917–18.

During the next 20 years he expanded Bethlehem's capacity to supply standard and special steels, so that in the Second World War the Corporation provided 37 million tons of steel and built over 1000 ships for the United States and her allies.

Mr Grace retired as chief executive of the Corporation in 1957, although he remained honorary chairman. He had been a member of The Iron and Steel Institute since 1914, and in 1942 he was awarded the Bessemer Gold Medal for his service to the iron and steel industry both in the United States and overseas, and particularly for his friendly co-operation with the industry in Britain.

Letter to the Editor

Thermal and magnetic analysis of an Fe–Ni alloy by an electron beam technique

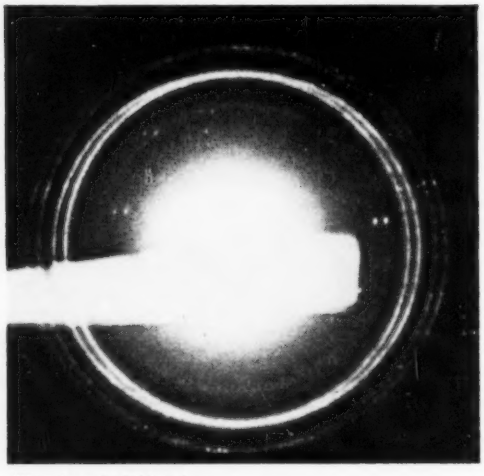
IN THE PRESENT STUDY, an electron beam of a certain wavelength was used to heat a test-piece, for diffraction analysis of its crystal structure, and for magnetic analysis using the Lorentz effect.

Invar powder (35 at-%Ni) was used as a specimen for the experiment. The particles in the specimen (grain size about 1000 Å) were held to the sharp edge of a razor blade acting as permanent magnet (remanence about 10000 G). In this way the Invar particles were kept in the saturation induction (15000 G[1]). An electron beam (0·1 mm cross-section, 0·05 mA current, and 0·0299 Å wavelength) grazed these magnetized particles to produce their diffraction pattern. In this case, not only should the path of the electrons become deflected by the magnetic field of the specimen,[2] but also the temperature of the specimen should be raised through bombardment by the fast electrons.

To investigate the relationship between the temperature and magnetic induction of the specimen, the following process of double exposure was carried out.

First, the diffraction diagram produced from the specimen when kept as cold as possible, i.e. nearly at room temperature (about 25°C) was photographed. To do this, great care had to be taken to avoid preheating the specimen by the incident electron beam. The exposure needed for the photograph was only ½ s.*

* It has already been reported that this temperature remains at about 40°C, because a crystalline diffraction pattern was observed of the solid paraffin (melting point: 45–50°C) under the same conditions as for the cold specimen in the present experiment (*cf.* S. Yamaguchi: *Z. angew. Physik*, 1956, **8**, 221–222).



Wavelength: 0·0299 A
Camera length: 495 mm
Positive enlarged by about ×4

A *Double diagram consisting of diffraction rings from the cold and the hot specimen. Ring eccentricity occurs owing to the Lorentz effect*

Second, the diffraction diagram produced from the specimen when preheated by continuous bombardment with the incident electrons for 2 min was superimposed upon that of the former cold specimen. During this process, the position of the specimen and that of the photographic plate relative to the incident beam, and the intensity and wavelength of the incident electrons were all kept constant. The double diagram thus obtained is shown in Fig.*A*. It should be noticed that the cold and the hot specimen are eccentric, which means that the magnetic state of the former specimen differs from that of the latter. Figure *A* shows a typical pattern characteristic of the face-centred cubic lattice, i.e. of the austenite (lattice constant 3·52 Å). This verifies crystallographically that the present specimen is a solid Fe–Ni solution.

The eccentricity ΔZ of the rings which can be measured in Fig.*A* readily gives the difference ΔB between the magnetic induction of the cold and hot specimen. It is

$$\Delta Z = \frac{eL\lambda l}{h}\Delta B \qquad (1)$$

where e is the electron charge ($1{\cdot}6\times10^{-20}$ emu (cgs)), L is the camera length (495 mm), h is Planck's constant ($6{\cdot}6\times10^{-27}$ erg/s), λ the wavelength of the applied electrons (0·0299 Å), and l the effective range of the magnetic field. From Fig.*A* $\Delta Z = 0{\cdot}4$ mm and therefore $\Delta B \simeq 4000$ G from equation (1), if l is assumed to be about 3 μ. This ΔB value is about equal to the difference between the saturation induction of Invar (15000 G) and the remanence at the razor edge (10000 G). This means that the temperature of the hot specimen has exceeded the Curie point of Invar (about 250°C),[3] so that it has become paramagnetic. In fact, it was observed that some of the Invar particles attracted at the razor edge fell off under the force of gravity when they had been irradiated sufficiently by the electron beam.

In Fig.*A* some weak rings characteristic of the ferromagnetic inclusion (Fe_3O_4) of the higher Curie point (575°C)[1] can be seen. This oxide caused the particles of the Invar specimen to remain attracted at the razor edge even after the Curie point of Invar had been exceeded. This implies that the temperature of the hot specimen remained below 575°C. Here the existence of the Fe_3O_4 inclusion in the specimen was verified crystallographically by diffraction. Thus it was possible to estimate the Curie point of an Fe–Ni alloy, e.g. that of Invar.

S. YAMAGUCHI

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REFERENCES

1. R. M. BOZORTH: 'Ferromagnetism', pp.713 and 870; 1956, Bell Laboratories Series, D. Van Nostrand Co., Princeton, USA.
2. S. YAMAGUCHI: *JISI*, 1958, **188**, 351–352.
3. E. A. OWEN and Y. H. LIU: *JISI*, 1949, **163**, 132–137.

NEWS

Announcements and News of Science and Industry

THE IRON AND STEEL INSTITUTE

Elections to Council

The following elections were announced after the meeting of Council on 22 October:

Member of Council

Mr N. C. Lake (*Member*), deputy managing director, Head Wrightson and Co. Ltd.

Honorary Members of Council

Dr N. P. Allen, M.MET., F.R.S. (superintendent, Metallurgy Division, National Physical Laboratory) and Dr W. O. Alexander (assistant research manager, Metals Division, ICI) now represent The Institution of Metallurgists on the Council in place of Mr E. J. Bradbury and Mr W. E. Bardgett. Dr Allen already serves on the Council as an Additional Honorary Member.

Special meeting in USA October – November 1961

The Council hope shortly to be able to announce full details of the programme for the Institute's Special Meeting in the USA and Canada next year. An outline of the itinerary was given in the September 'News' (p.91). As previously announced, the Council has accepted with pleasure an invitation from the Metallurgical Society of the American Institute of Mining, Metallurgical and Petroleum Engineers (AIME) to visit the USA in the autumn of 1961.

The provisional programme provides for an official welcome in New York City on **Thursday, 19 October**, but it is anticipated that some members will arrive a day or two earlier.

Members will be able to travel to and from the USA by normal sea and air routes, but in addition aircraft will probably be chartered for Atlantic crossings at substantially reduced cost. Provisional dates for these crossings are: to New York, **Wednesday, 18 October;** from New York, **Wednesday, 8 November 1961.**

Full information and quotations of costs will be circulated in the spring of 1961.

NEWS OF MEMBERS

Mr **J. L. M. Bevan** has joined The Llanelly Steel Co. (1907) Ltd.

Mr **M. W. Butler** has been appointed technical sales representative with Atlas Steels (England) Ltd.

Mr **H. Darnell** has been appointed a director and general works manager of Steel, Peech and Tozer.

Mr **A. C. Dennis** has been appointed to the board of Osborn Foundry and Engineering Co. Ltd.

Mr **J. T. W. Dewar** has been appointed chairman of Shepcote Lane Rolling Mills Ltd.

Mr **W. K. V. Gale** has joined the staff of *The Engineer*.

Mr **G. E. D. Halahan** has been appointed a director and general works manager of Round Oak Steel Works Ltd.

Mr **A. A. Hinchliffe** is now a graduate apprentice production-metallurgist with Rolls-Royce Ltd, Aero Engine Division.

Mr **C. E. Holmstrom,** J.P., has retired from the board of Shepcote Lane Rolling Mills Ltd, and Firth-Vickers Stainless Steels Ltd.

Mr **P. M. Kelly** has been appointed lecturer in metallurgy at Leeds University.

Mr **A. K. Kirk** has been elected a Sheriff of the City of London.

Mr **F. A. Kirk** has been appointed to the board of the Titanic Steel Company Ltd.

Mr **Z. S. Kopczynski** is now with Sulzer Brothers Ltd, Winterthur, Switzerland.

Mr **N. D. Macdonald** has been appointed general works manager of the Workington Iron and Steel Company.

Mr **Q. C. McMillan** has been appointed a director of the Clyde Alloy Steel Company.

Mr **A. Pearson** has been appointed a director of the Clyde Alloy Steel Company.

Monsieur **P. Rousseau** is now with the Chambre Syndicale de la Sidérurgie Française in Paris.

Mr **P. J. Rowling** is now a senior metallurgist with the Ford Motor Company Ltd.

Mr **J. Williams** has been appointed a local director of Samuel Osborn and Co. Ltd.

Obituary

D. Luther Phillips (*elected 1933*), of Swansea, in October.

F. E. C. Probyn (*elected 1954*), of Ebbw Vale, on 15 October.

Richard Sharp (*elected 1938*), of Nottingham, on 17 September.

Vincent E. Upton (*elected 1948*), of Manchester, on 10 October.

VEREIN DEUTSCHER EISENHUTTENLEUTE

Presentation of The Medal of The Iron and Steel Institute

To mark the centenary of the Verein deutscher Eisenhüttenleute, the Council of The Iron and Steel Institute presented the Verein with The Iron and Steel Institute Medal. The presentation was made by the President of the Institute, Mr W. F. Cartwright, D.L., J.P., at a meeting in Düsseldorf on 3 November. A report of the presentation will be given in an early issue of the *Journal*.

SOCIETE FRANÇAISE DE METALLURGIE

Presentations

At the recent Journées Métallurgiques d'Automne in Paris the following presentations were made:

Grande Medaille H. Le Chatelier: Monsieur Marc Allard (*Member*)

Medaille Réaumur: Dr Walter Siegfried (*Member*)

Prix Rist: Monsieur André Constant (*Member*) and Monsieur Jacques Boghen.

INSTITUTE OF WELDING

Conference on welding standardization

The first of these conferences will be held at the Institute of Welding, 54 Princes Gate, London SW7, on 7 December 1960. The theme will be the role of welding standardization in production and export, and the principal subjects for discussion will be specifications for steels, and standards for welded structure. The conference is open only to individual corporate members of the Institute and nominees of industrial corporate members.

School of Welding Technology courses

Courses at the School for the remainder of the session November 1960–March 1961 include:

D.15/2	Brazing: technology and design	16–20 Jan.
D.32	Design for welding in thermoplastics	30–31 Jan.
D.5/3	Non-destructive weld examination	13–17 Feb.
D.22	Welding of atomic energy plant	27 Feb.–3 Mar.
D.17/1	Advanced course for welding engineers	13–17 Mar.
D.4/2	Resistance welding: technology and design	27–30 Mar.

Full details of these courses are available from the secretary of the Institute of Welding.

BRITISH WELDING RESEARCH ASSOCIATION

UK welding experts visit USSR

Four senior members of the staff of the British Welding Research Association recently visited the USSR. They were Dr R. Weck, Mr H. F. Tremlett, Dr A. A. Wells, and Mr P. T. Houlcroft. While in Moscow they attended a welding exhibition, and they were particularly interested in the exhibits of cold pressure welding (especially of dissimilar metals), friction welding, and diffusion welding.

The party felt that there is in the USSR a clearer realization of the key role played by welding in all industries than exists in the UK. Research effort is on a much greater scale, but taking account of the difference in the populations of the two countries the UK effort stands comparison. In the USSR the work is generally of the highest quality although the emphasis is placed to a greater extent on problems arising in the application of new processes than on fundamental work undertaken for the sake of increasing knowledge.

INSTITUTION OF ELECTRICAL ENGINEERS

Faraday Lectures, 1960–61

The Institution of Electrical Engineers has announced that The Faraday Lectures for 1960–61 will be given by Mr L. J. Davies, C.B.E., M.A., B.SC., M.I.E.E., director in charge of research and education, Associated Electrical Industries (Rugby) Ltd. The title of the lecture is 'Transistors and all that', and it will be delivered at the following centres: Bristol, Swansea, Manchester, Leeds, Portsmouth, London, Birmingham, Leicester, Edinburgh, and Newcastle.

Admission is free by ticket from the honorary secretary of the branch of the Institution in which the lecture is delivered. Names and addresses of honorary secretaries, and dates of the lecture are available from the secretary of the Institution of Electrical Engineers, Savoy Place, London WC2.

EDUCATION

Coke and coal scholarships

University scholarship schemes for 1961 have been announced by the British Coking Industry Association and the National Coal Board.

The object of the BCIA scheme is to provide suitable candidates with a university course in chemical engineering or fuel technology, followed by a period of organized post-graduate practical training to equip them for responsible positions in the coking industry, particularly in plant management. Full details of the scheme are available from the Secretary, British Coking Industry Association, 74 Grosvenor Street, London W1.

The NCB scholarships are offered to school leavers and those already employed in the industry, to fit them for a career in the industry leading to posts of high managerial and technical responsibility. All scholars are expected to remain in the coal industry for at least three years after graduation, and they will normally enter the Board's scheme of directed practical training, which combines technical instruction and practice with tuition in the fundamentals of good management. A booklet 'Conditions of award' is available from the Staff Department, National Coal Board, Hobart House, Grosvenor Place, London SW1, or any of the divisional headquarters of the Board at Edinburgh, Newcastle, Doncaster, Manchester, Nottingham, Dudley (Worcs.), Cardiff, or Dover.

Research fellowships in metallurgy

Graduates with research experience in metallurgy, solid-state physics, or physical chemistry who desire an opportunity to do metallurgical research on a subject of their choice are invited to apply for the following senior research fellowships tenable in the Department of Metallurgy, of the University of Sheffield.

J. H. Andrew Research Fellowship
C. H. Desch Research Fellowship
The United Steel Companies Research Fellowship

These fellowships have been made possible by the generosity of industry. Fellows will have a wide choice of research topic, though it is hoped that one of them will take a special interest in the application of modern physical techniques to metallurgical problems. The starting salary will normally be £1000 pa but a higher salary may be paid to a successful candidate with outstanding qualifications and experience. Normal tenure will be five years but the appointment will be for two years in the first instance and thereafter will be renewable annually. There will be annual increments of £50 pa and provision will be made for superannuation under the F.S.S.U.

Applications (three copies) including the names and addresses of referees, should reach the Registrar (from whom further particulars can be obtained) as soon as possible, at St George's Square, Sheffield 1.

Recruiting metallurgists

An attractive two-colour leaflet aimed at giving 'some indication of what metallurgy is in the context of science and industry today, and of what metallurgists do' has recently been issued by The Institution of Metallurgists to schools with sixth forms, and youth employment officers throughout the country. It puts the case briefly for a career in metallurgy, pointing to the contemporary importance of metals ('the average amount of metal used per head of the population of a country is a reliable guide to its state of civilization and development') and describes openings for metallurgists, ranging from pure research to mining uranium or making steel. The leaflet ends with a short list of suggested further reading.

The Institution of Metallurgists, 4 Grosvenor Gardens, London SW1, is interested to hear from anyone concerned with careers guidance or youth employment who could help to bring the leaflet to the attention of potential young metallurgists.

Historic books on mining and kindred subjects

Through the good offices of the president and members of the Institute of Mining and Metallurgy, the collection of rare and historic books owned by Mr Robert Annan is being exhibited at the Science Museum, South Kensington, London, from 15 November to 31 December 1960. These rare books deal with mining, assaying and metallurgy, mining law, and mineralogy.

The Science Museum is open daily from 10.0 am to 6.0 pm, Sundays 2.30 pm to 6.0 pm, and admission is free at all times.

CONTRIBUTORS TO THE JOURNAL

Miss M. Odgers—Research assistant, GKN Group Laboratory, Wolverhampton.

Miss Mary Odgers was educated at Notre Dame High School, Norwich, then trained under a government emergency scheme for metallurgical chemists, at Wednesbury Technical College. From 1942 to 1944 she was with the Metropolitan Cammell Carriage and Wagon Company in Wednesbury, then in 1945 she was appointed an assistant chemist at the Bilston works of Joseph Sankey and Sons Ltd. She transferred to her present post in the research metallurgy section of the GKN Group Laboratory in Wolverhampton in 1948.

K. A. Salmon, M.MET., PH.D.—Welding metallurgist, English Electric Co. Ltd, Whetstone.

Dr Salmon attended the County Grammar School for Boys, at Altrincham, before entering the metallurgy department of Sheffield University, from which he graduated in 1955 with the degree of B.MET.(HONS.). In the following year he was awarded his M.MET. for research into the purification of pig iron by electrolysis, and he received his doctorate in 1959 for the thesis which forms this present paper.

J. F. Sewell, M.SC., F.I.M.—Liaison metallurgist, Samuel Fox and Co. Ltd, Sheffield.

James Fowler Sewell was born at Horwich, Lancs., and after graduating with honours in metallurgy at Manchester University, underwent a two-year apprenticeship with The United Steel Companies Ltd. During this period he was granted an M.SC. degree for a thesis dealing with the production of railway tyres. Most of his subsequent 25-years' service with United Steels has been with Samuel Fox and Co. Ltd, the alloy-steel branch where he has worked in production, technical, and sales departments. On two occasions he has been seconded to Government Departments. In 1942 he became chief metallurgist for three years to the Distington Hematite Iron Company at Workington, an alloy-steel producing unit of the Ministry of Supply, and in 1951 he went to Washington, USA, for 12 months as adviser on steel alloys to the Ministry of Materials delegation to the International Materials Conference. He returned to the UK to spend several months with the Alloy Steel Control before rejoining Samuel Fox and Co. Ltd.

R. F. Johnson, B.SC., A.I.M.—Research investigator, Research and Development Department, The United Steel Companies Ltd, Rotherham.

Born in Manchester, Mr Johnson was educated at Manchester University where he received his B.SC.(HONS) in metallurgy in 1943. He then became a member of the research staff at Hadfields Ltd, Sheffield, where he was engaged in development work on high-temperature steels. In 1951, after a brief period at David Brown Foundries, Penistone, as research metallurgist, he joined The United Steel Companies Ltd where he has been chiefly concerned with investigations in fatigue. At present he is responsible for research work on engineering steels.

NEWS OF SCIENCE AND INDUSTRY

Second sinter plant at Workington

A new £2½-m. sinter plant is being opened at Workington Iron and Steel Company on 6 December by HRH Prince Harald, Crown Prince of Norway.

The existing sinter plant at Workington, which has been in operation since 1943, has successfully shown the advantages of using sinter and as additional quantities are now needed the decision was taken to build the new plant.

Norwegian iron ore is particularly suitable for the acid Bessemer steelmaking process employed at Workington and it is supplied in the form of a concentrate which is finely powdered and therefore demands a sintering technique. The company already use up to 150000 tons of these concentrates each year, which will be increased to 400000 tons when the new plant is in operation. This represents about 60% of the raw material intake.

Increased demand for stainless steel

Firth–Vickers is doubling its capacity of 400 tons a week of stainless steel wide strip in coils, as a result of the high rate of demand from the motor industry and the makers of kitchen equipment. Bulk production is said to have reduced prices to a point where stainless steel is no longer more expensive than chromium plating. A £2 m. plant extension at Sheffield is expected to be completed during the second half of 1961.

National Chemical Laboratory Open Days

The National Chemical Laboratory held their Open Days between 19 and 21 October 1960. The Laboratory carries out fundamental and basic research not considered appropriate either to industry or the universities but which is likely to have wide application. The current research programme includes the prevention of corrosion of metals as one of its primary objectives. Much of the present work of the Corrosion Group is concerned with the corrosion of iron and steel in the environments in which they are used: in water, in air, or in soils. The corrosion rates of iron in water are examined and measured over an extensive temperature range. Underground corrosion of iron and steel is proving to be mainly a microbiological problem.

Another aspect of the work on corrosion is the mode of action of inhibitors (corrosion preventers) which is being examined by electrochemical and radiotracer methods. It was demonstrated how much can also be done simply by designing and making crevice-free joints and avoiding sharp bends in a system, or by chemical treatment of water. Improved methods for achieving this are currently being studied at the Laboratory.

Appointments at RTB Spencer works

Senior appointments recently made to the production, administration, and engineering staffs of the Spencer Works, now under construction at Llanwern, near Newport, Mon., include the following:

Mr R. A. Lake (*Member*), chief engineer
Mr A. J. Burgess (*Member*), ironmaking manager
Mr D. Gray (*Member*), ore-preparation and sinter-plant manager
Dr M. Morrison, chief civil engineer
Mr D. J. Jones (*Member*), cold mill manager
Mr F. R. Gillett, manager, central control and planning office
Mr J. Fisher, hot-mills manager
Mr W. R. Harrison, blast-furnace manager
Mr R. L. Johns, chief mechanical engineer

Mr L. T. Shore, steel-plant manager
Mr G. Short (*Member*), assistant works manager, rolling mill
Mr J. C. Thickens (*Member*), chief metallurgist
Mr R. H. Parker (*Member*), works manager
Mr H. F. Padbury (*Member*), assistant works manager, coke, iron, and steel
Mr R. Raby, coke-ovens manager
Mr O. W. Reynolds, education and training officer
Mr S. I. Webber, assistant chief accountant
Mr D. Benallick, chief accountant and general manager
Mr L. B. Davies, commercial manager
Mr F. C. Fone, office manager
Mr W. M. Goatman, public relations officer
Mr K. Hollingsworth, manager, staff and labour relations department
Mr D. Knights, traffic manager
Dr G. G. Mathew, medical officer.

UK-built cranes for Canada

In January of this year, Cowans Sheldon and Co. Ltd, the Carlisle crane-makers, won a contract for two giant diesel railway breakdown cranes for the newly formed Quebec Cartier Mining Company in Northern Quebec Province, Canada.

Temperatures at the mines fall to —60°F and, particularly when the snows melt in the spring, the ore-laden trains of 120-ton wagons may well be derailed, blocking the only outlet to the port of shipment.

To rerail locomotives and rolling-stock, giant cranes are needed to haul them from the morasses resulting from the melting snows. The mining company decided to order one crane of 250 tons lifting capacity and another of 150 tons. These two cranes are the only major items of equipment for this multi-million dollar project to be ordered outside the North American continent. The larger crane was designed, built, tested, and despatched within 10 months of receipt of order. The total value of the contract was more than £200000.

Company News

General Refractories Ltd, sole UK licensees for the manufacture and sale in the UK of metal-cased basic bricks produced under the Heuer Patents (British patent), and marketed under the name of 'Ferroclad', announce that in view of the greatly increased demands for these bricks, particularly in the construction of all-basic furnaces, they are making the patents available to other manufacturers. In future *Pickford Holland and Co. Ltd* will also market bricks manufactured under the Heuer Patent process, under the trade name of 'Metalclad'.

Electrical accidents in 1959

A recent report on electrical accidents and their causes in 1959 gives the total number of electrical accidents reported under the Factories Acts last year as 738, including 34 fatal accidents, and 143 cases of welders' conjunctivitis or 'eye-flash'. The total exceeds the figures for 1957 or 1958, but there has, in fact, been little variation in the figures over the last ten years, despite the ever-increasing use of electric machines, apparatus, and installations in all branches of industry.

A further 118 fatal accidents, not reportable under the Factories Acts, came unofficially to the notice of the Factory Inspectorate. The figures of reportable accidents are analysed by cause, location, voltage, apparatus, and occupation, in tables set out in the report.

Investigation of causes showed that nearly half the total accidents resulted from ignorance, negligence, forgetfulness, and inadvertence, while mistakes by persons other than those injured accounted for one-fifth of the total. Other important causes were failure to earth equipment, whether portable or fixed, and the essentially dangerous business of testing.

The report is available from HM Stationery Office or through any bookseller, price 5*s* 6*d* net.

Indian research, 1959–60

The report of the National Metallurgical Laboratory, Jamshedpur, India, for 1959–60 shows an increasing trend in much of the Laboratory's works towards industrial implementation of research. Investigation of indigenous raw materials is being balanced by their exploitation on an industrial scale, and much of the Laboratory's work in the period under review has been with pilot plants, some of which have been equipped from funds provided by the UK under the Colombo Plan. The Laboratory has developed a number of patented processes, some of which it has released free of royalties to small developing industries, while others which have been applied commercially provide an income to the Laboratory.

In his foreword to the report, Sir J. J. Ghandy, chairman of the Executive Council of the National Metallurgical Laboratory, pays tribute to the work of the Laboratory's director, Dr B. R. Nijhawan.

INDUSTRIAL PUBLICATIONS RECEIVED

Acheson Colloids Ltd have produced a booklet containing a full list of their 'Gredag' greases and compounds.

Leaflet AHF 2/660 from Wild-Barfield Electric Furnaces Ltd describes the firm's 2½-kW induction heating equipment.

Second in a series is a leaflet 'What we make–2' from the Incandescent Gas Atmospheres Division of the Incandescent Heat Co. Ltd.

Recent literature from Henry Wiggin and Co. Ltd includes 'Wiggin Nickel Alloys no.58', 'Developments in Nimonic heat-resisting sheet alloys', and 'Some applications of Nimocast heat-resisting alloys'.

Power House Components Ltd briefly describe their range of 'Wayne' patent self-winding electric cable reels in a new leaflet.

Crodafluid 9040 oil-type rust preventive is fully detailed in a booklet from Croda Ltd.

The September issue of 'The English Electric Journal' includes papers on 'Electrical control systems in heavy industry, by H. S. Brown and J. C. Christie, and 'Ingot buggie and shuttle car scheme at the Port Talbot Works of the Steel Company of Wales', by R. B. Larkinson.

CHANGES OF ADDRESS AND TITLE

Negretti and Zambra Ltd have opened a branch at 38 Dean Street, Newcastle-upon-Tyne.

Quasi-Arc Ltd are now trading in the name of the parent company, The British Oxygen Company Ltd. Invoicing will continue in the name of Quasi-Arc until 31 December.

The de Havilland Aircraft Company Ltd and *de Havilland Propellors Ltd* have been merged by de Havilland Holdings assuming the name of The de Havilland Aircraft Company Ltd and acquiring all the assets and liabilities of the other two companies.

Foseco Holdings Ltd is the name of the holding company formerly known as Foundry Services Holdings Ltd, and the managing company formerly known as Foundry Services International Ltd now becomes *Foseco International Ltd*.

FORTHCOMING CONFERENCES AND EXHIBITIONS

Agglomeration

The first American-held international symposium on agglomeration, scheduled for the Sheraton Hotel, Philadelphia, for 12–14 April 1961, has been announced by the sponsoring organization, the American Institute of Mining, Metallurgical, and Petroleum Engineers.

The underlying theme will be the basic mechanisms common to agglomeration processes in general. Specifically, the symposium will deal with the processes of sintering, pelletizing, nodulizing, briquetting, powder metallurgy, ceramic bonding, and related processes. Areas of application will be not only ferrous and non-ferrous ores, but also will include carbonaceous materials, ceramics and other non-metallics.

Emphasis will be, principally, on the fundamental aspects of agglomeration. Descriptions of existing plant will be limited to examples and proof of application. Further details of the symposium are available from the AIME, 29 West Thirty-ninth Street, New York 18, NY.

Industrial finishes

The first international Industrial Finishes Exhibition and Convention will be held at Earls Court, London, from 8 to 11 May 1961. The convention will be held in special meeting rooms at Earls Court and will consist of two sessions on each day of the exhibition. Preprints of papers presented will be available and delegates will be invited to participate in discussions at these sessions.

Proposals for suggested papers and speakers are at present being considered, and further information is available from the organizers, Scientific Surveys Ltd, Exhibition Division, 97 Old Brompton Road, London SW7.

American Foundrymen in San Francisco

The American Foundrymen's Society will hold its Castings Congress and Exposition of equipment and supplies in San Francisco on 8–12 May 1961. The congress will comprise some 65 technical sessions, the result of a year's work by ten technical divisions of the AFS. Complete details of the congress and exposition are available from American Foundrymen's Society, Golf and Wolf Roads, Des Plaines, Ill., USA.

Construction equipment at Crystal Palace

After an interval of 25 years the Crystal Palace is again to become the site of a major international exhibition. In June 1961 a new exhibition, the Construction Equipment Exhibition, will, by arrangement with the London County Council, be launched on a 25-acre area at the Crystal Palace. The exhibition grounds will include the area formerly occupied by the 1851 Exhibition Palace itself and also the terraced gardens designed by Sir Joseph Paxton over 100 years ago.

Organization of the exhibition will be carried out by Industrial and Trade Fairs Ltd, Drury House, Russell Street, London WC2, to whom all enquiries should be addressed.

Metallurgy of beryllium

The Institute of Metals is holding a three-day international conference on 'The metallurgy of beryllium' in London on 16, 17, and 18 October 1961. The intention is to publish and discuss a great mass of hitherto unpublished original work of beryllium and to cover metal fabrication, physical and mechanical properties, and metal physics, i.e. the whole field of the metallurgy of beryllium with the exception of extraction processes. The conference will be organized by the Institute's Nuclear Energy Committee.

The organizing committee invites offers of original papers for the conference and requests that prospective authors shall submit firm titles and synopses of their papers by 1 January 1961 and the final manuscripts, in duplicate, not later than 1 April 1961. Prospective authors are asked to advise the secretary, as soon as possible, of the topics on which they intend to offer papers.

Papers will be issued in preprint form in advance of the conference and will later be published promptly, together with reports of the discussions, in bound form. Correspondence regarding the conference should be addressed to the Secretary, The Institute of Metals, 17 Belgrave Square, London SW1.

DIARY

5 Dec. INSTITUTE OF BRITISH FOUNDRYMEN, SHEFFIELD BRANCH—Lecture, '*Engineering the layout of*

a jobbing core shop', by A. Atherton—Technical College, Pond Street, Sheffield, 7 pm.

6 Dec. INSTITUTE OF WELDING, SLOUGH SECTION—Lecture, '*Argon welding process*', by F. W. Copplestone—Lecture Hall, Community Centre, Farnham Road, Slough, 7.30 pm.

7 Dec. MANCHESTER METALLURGICAL SOCIETY—Lecture, '*The relationship between physical test results and engineering performance*', by Dr J. H. Lamble—Manchester Literary and Philisophical Society, George Street, Manchester, 6.30 pm.

7 Dec. THE SOCIETY FOR ANALYTICAL CHEMISTRY—Meeting on the flask combustion technique—Imperial College, Exhibition Road, London SW7, 6.30 pm.

7 Dec. THE INSTITUTION OF MECHANICAL ENGINEERS (FOR BRITISH NUCLEAR ENERGY CONFERENCE)—Symposium on the Dounreay fast reactor —1 Birdcage Walk, London SW1.

7 Dec. THE INSTITUTION OF METALLURGISTS—Informal Christmas dinner and talk '*Scientific information—the rake's progress*', by B. Fullman—Ayrton Hall, Imperial College, Exhibition Road, London SW7, 6.15 for 7 pm.

7 Dec. INSTITUTE OF PETROLEUM—Lecture, '*The changing energy pattern in Europe and its possible effect on product-mix*', by M. E. Hubbard —61 New Cavendish Street, London W1, 5.30 pm.

8 Dec. STAFFORDSHIRE IRON AND STEEL INSTITUTE—Lecture, '*The Ajax furnace and process*', by A. Jackson—Training Centre, Stewarts and Lloyds Ltd, Bilston, 7.30 pm.

12 Dec. NORSK METALLURGISK SELSKAP—Meeting (in Norwegian) '*Recent developments in electric smelting furnaces for calcium carbide*'—Rosenkrantzgaten 7, Oslo, Norway.

12–15 Dec. AMERICAN NUCLEAR SOCIETY—Winter meeting—Mark Hopkins Hotel, San Francisco.

12 Dec. LINCOLNSHIRE IRON AND STEEL INSTITUTE—Lecture, '*The technique of vertical and horizontal rolling*', by T. Hessey—North Linsey Technical College, Scunthorpe, 7.30 pm.

14 Dec. INSTITUTE OF WELDING—Lecture, '*Welding of transportation pipelines*', by R. J. Wright—54 Princes Gate, London SW7, 7.30 pm.

14 Dec. SOCIETY FOR INSTRUMENT TECHNOLOGY—Lecture, '*Speed control of aircraft gas turbines for jet propulsion*', by R. J. Walsh—Manson House, Portland Place, London W1, 7 pm.

15–16 Dec. POWDER METALLURGY JOINT GROUP—Winter meeting—Church House, Great Smith Street, London SW1 (*See p.352, November issue.*)

15 Dec. INSTITUTE OF MINING AND METALLURGY—Meeting—Geological Society, Burlington House, Piccadilly, London, W1, 5 pm.

15 Dec. NORTH WALES METALLURGICAL SOCIETY—Joint meeting with the Society of Instrument Technology, '*Instrumentation in steelmaking*', by Dr P. Bacon—Lecture Theatre, Flintshire Technical College, Connah's Quay, nr. Chester, 7 pm.

16 Dec. WEST OF SCOTLAND IRON AND STEEL INSTITUTE—Lecture, '*Recent developments in refractories for iron and steelmaking*', by R. Malcolm—39 Elmbank Crescent, Glasgow, 6.45 pm.

19–20 Dec. INSTITUTE OF PHYSICS AND PHYSICAL SOCIETY—Conference on statistical mechanics—Queen Mary College, London E1.

20 Dec. INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND—Joint meeting with Institute of Marine Engineers, Scottish section, and Greenock Association of Engineers and Shipbuilders, '*Developments in marine steam turbine design*', by T. W. F. Brown—39 Elmbank Crescent, Glasgow, 6.30 pm.

4 Jan. INSTITUTE OF PETROLEUM—General meeting—61 New Cavendish Street, London W1, 5 pm.

5 Jan. ROYAL INSTITUTION OF NAVAL ARCHITECTS—Third Amos Ayre Lecture by A. Hunter—10 Upper Belgrave Street, London SW1, 4.45 pm.

9 Jan. INSTITUTE OF BRITISH FOUNDRYMEN, SHEFFIELD BRANCH—Lecture, '*Pattern equipment for shell moulding*', by E. C. Rowen—Technical College, Pond Street, Sheffield, 7 pm.

9 Jan. LINCOLNSHIRE IRON AND STEEL INSTITUTE—Lecture, '*Engineering for nuclear power*', by Dr K. J. Wooton—North Lindsey Technical College, Kingsway, Scunthorpe, 7.30 pm.

10 Jan. ROYAL INSTITUTE OF CHEMISTRY, KENT SUB-SECTION—Lecture, '*Science and archaeological investigation*', by H. M. W. Hodges—Technical College, Mayfield Hall Annexe, Pelham Road, Gravesend, 7.30 pm.

11 Jan. INSTITUTE OF WELDING, SOUTH LONDON BRANCH—Lecture, '*Low alloy steel welding*', by Dr E. Freeth—54 Princes Gate, London SW7, 7.30 pm.

11 Jan. NORTH WALES METALLURGICAL SOCIETY—Lecture, '*Steelmaking for flat-rolled products*', by R. Mayorcas—Lecture Theatre, Flintshire Technical College, Connah's Quay, nr. Chester, 7 pm.

11 Jan. MANCHESTER METALLURGICAL SOCIETY—Lecture, '*Modern methods of metallurgical analysis*', by K. M. Bills—Manchester Literary and Philosophical Society, George Street, Manchester 6.30 pm.

11 Jan. ROYAL SOCIETY OF ARTS—Lecture, '*Ergonomics—fitting the job to the worker*', by Dr C. B. Frisby —John Adam Street, London WC2, 6 pm.

12 Jan. STAFFORDSHIRE IRON AND STEEL INSTITUTE—Lecture and film show, '*Prospecting for oil*'—Training Centre, Stewarts and Lloyds Ltd, Bilston, 7.30 pm.

13 Jan. NORTH EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS —Andrew Laing Lecture, '*Some post-war developments in naval construction*', by Sir A. J. Sims—Literary amd Philosophical Society lecture theatre, Newcastle-upon-Tyne, 6.15 pm.

BRITISH IRON AND STEEL INDUSTRY TRANSLATION SERVICE

The following translations are now available, in addition to those given on page 356 of the November 1960 issue of the *Journal*:

Combined platinum-carbon evaporation as a preparatory technique in electron micrography. GÜNTHER, F. W., and RAAB, D., *Neue Hütte*, 1959, Feb., pp.113–115. (£1 10*s*. 0*d*.) **[1571**

Fault location in sheets by ultrasonic lamda waves. WIEGAND, H., and HENTZE, H., *Materialprüfung*, 1960, Feb. 20, pp.45–50. (£4 15*s*. 0*d*.) **[1686**

The reaction of metallurgical workers to technical innovations. JÜRES, E. A., *Stahl u. Eisen*, 1960, March 31, pp.429–437. (£4 10*s*.) **[1711**

The Dr Förster Institute (for non-destructive testing) Reutlingen. FÖRSTER, F., *Materialprüfung*, 1960, (2), pp.65–68. (£3 10*s*. 0*d*.) **[1724**

The effect of the duration of the load on the hardness of metals and their alloys. SHISHOKIN, V. P., *Zhur. Tekn. Fiziki*, 1938, **8**, (18), pp.1613–1628. (£6 10*s*. 0*d*.) **[1766**

Development of the open-hearth furnace with a new profile. BOELENS, E., *Radex Rund.*, 1960, April, pp.71–85. (£5) **[1767**

The nature of the solid solution of boron in alpha-iron. SHEVELEV, A. K., *Dok. Akad. Nauk*, 1958, (3), pp.453–456. (£3) **[1797**

9%Cr–1%Mo steel tubes for use in modern power boilers. OMORI, J., *et al.*, *Sumitomo Met.*, 1955, April, pp.98–109. (£10) **[1801**

The Rourkela iron and steelworks in India. HEINRICH, H., *Stahl u. Eisen*, 1960, Feb. 18, pp.197–206. (£5 10*s*. 0*d*.) **[1843**

The steel tube as structural element. JAMM, W., *Tech. Mitt.*, 1959, March, pp.89–94. (£4 5*s*. 0*d*.) **[1879**

Improved heat transfer to water through artificial roughening (grooving) of surfaces in reactors or heat exchangers. GRASS, G., *Atomkern-Energie*, 1958, (8–9), pp.328–331. (£2 15*s*. 0*d*.) **[1882**

1886, 1888, 1915, 1916: Papers from International discussions on long time behaviour of high temp. steels, Düsseldorf, 24–25 June 1960.

The development and introduction of a new ferritic steel for superheated steam pipes and superheater tubes. BIHET, O. L., *et al.*, Paper No.13. (£4) **[1886**

Swedish proposals for definitions of terms used in high temperature testing and for the corresponding abbreviation symbols (in particular for static load testing). ENGSTRAND, G., Paper No.34. (£1 10*s*. 0*d*.) **[1888**

Influence of cooling rate, heat treatment, and solidification cross-section on room temperature properties and creep behaviour of a cast steel with 1%Cr, 0·9%Mo, and 0·3%V. GUT, K., and LÜLING, H., Paper No.17. (£3 10*s*. 0*d*.) **[1915**

High temperature behaviour of Cr–Mo–V steels: The influence of thermal treatment—comparison between the results obtained on rotors and on bars for high temperature bolts. ROQUES, C., and LE CREUSOT, Paper No.22. (£2 5*s*. 0*d*.) **[1916**

Load on roller bearings in the stands of continuous rod mills (with discussion). MÜNNIH, H., *Stahl u. Eisen*, 1960, Aug. 18, pp.1136–1147. (£9) **[1890**

Equilibrium of sulphur reaction between liquid, carbon-saturated iron, and lime–silica–alumina slags. SCHENCK, H., *et al.*, *Arch. Eisenhütt.*, Aug., pp.471–472. (£1 15*s*. 0*d*.) **[1893**

Resistance to flow in branch pipes. GRASS, G., and LÜTH, E., *Allgemeine Wärmetechnik*, 1958, (9), pp.185–189. (£2 10*s*. 0*d*.) **[1899**

Results of a comparison between the plug mill and pilger mill processes. BORISOV, S. I., from book: Proizvodstvo trub na ustanovkakh s avtomaticheskimi i piligrimovymi stanami, 1959, Metallurgizdat, Khar'kov, Ch.8, pp.320–326. (£3 5*s*. 0*d*.) **[1919**

ABSTRACTS OF CURRENT LITERATURE *Iron and Steel Manufacture and Related Subjects* AND BOOK NOTICES

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* Abstracts, the reference to which is marked with an asterisk, are or are to be made available as translations.

ABSTRACTS

These abstracts are also available on index cards in advance of publication in the *Journal*, each abstract being classified under the Universal Decimal system (UDC). Details and subscription notes can be obtained from the Secretary, The Iron and Steel Institute.

ORES—MINING AND TREATMENT

The softening of blast-furnace ores M. Prouza (*Hutn. Listy*, 1960, **25,** (3), 167–170) The significance and technological importance of a knowledge of the softening of iron ores are discussed. An instrument for measuring the thermoplastic properties of ores up to 1600°C was developed, and the results obtained with it are considered. The equipment consists of a graphite tube furnace in which ore briquettes are subjected to pressure. The deformation of the sample is recorded continuously.—P.F.

Rotary kiln linings J. Vosyka (*Hutník*, 1960, **10,** (3), 98–101) The design and choice of materials for the best performance and longest lining life in kilns used for roasting ores, coke, and cement are discussed with special reference to the particular experience and conditions at the author's works.—P.F.

Study of making briquettes of jacutinga (squamous dusty hematite) with a view to the production of sponge iron E. L. Vieira (*Bol. ABM*, 1960, **16,** April, 249–267) The manufacture of compressed briquettes by hydraulic or impact presses, using as binders, dextrin, tar, or sodium silicate and CO_2, is described, and the temp. used in pressing and the properties of the products are reported.—S.H.-S.

Replacing the firing hearth of the sintering machine N. A. Belokonenko (*Metallurg.*, 1960, (1), 12–13) The linings of the gas firing hearth have to be changed every six months and this takes about 48 h. The author suggests a reserve hearth which can be changed without much trouble in considerably less time. Diagrams are given.

Study of the sintering of some Spanish iron minerals. IV. The effect of additives on the production and quality of sinter irons. V. Sintering of Coto de Orconera carbonate. VI. Microradiography J. A. Boned Sopena (*Hierro y Acero*, 1960, **13,** Jan.–March, 289–319) A comprehensive description of various aspects of sinter production, with tables of experimental results, their chemical analyses, temp. curves, yields, and properties.—S.H.-S.

Obtaining self-fluxing sinters at the start of an industrial mixture of minerals J. A. Boned Sopena, A. Fillol Ciorraga, and J. Asensio Gonzalo (*Hierro y Acero*, 1960, **13,** April, 392–413) A comprehensive study of the effect on production of normal and self-fluxing sinters together with a review of the effect on granulometry of the MICUM test is presented.

The influence of technological factors on the properties and mineralogical composition of fluxed sinter D. A. Kissin and V. P. Pevtsov (*Stal'*, 1960, (7), 579–583) Increased basicity, higher iron content of the ore and finer grinding are suggested for improving sinter quality.

Perfecting the production of open-hearth sinter from Dashkesan ore S. I. Malyshev, Sh. F. Khoshtariya, P. P. Gladkoskok, and G. F. Radchenko (*Stal'*, 1960, (7), 584–590) Addition of 30–35% millscale gives a good sinter from this ore.

Automation for sinter plants D. E. Hamilton and R. L. Houlton (*Blast Furn. Steel Plant*, 1960, **48,** June, 569–579) The sintering process and its control, and present and future applications of automation to the process are discussed. Examples are given of the application of local process control, with a number of examples of feed and transport regulation.

Increase in sinter strand productivity by introduction into the mix of lime in excess of 25 kg/t sinter V. G. Malinovskii and A. S. Babii (*Stal'*, 1960, (7), 593) A note from Enakievo.

Production of fluxed sinter with a mixture of limestone and dolomite B. N. Starshinov, V. P. Onoprienko, D. P. Burdyukov, V. I. Khalimonova, and L. I. Sergienko (*Metallurg.*, 1960, (2), 6–7) The optimum humidity corresponding to the greatest vertical speed of sintering is about 6·5%. An increase of MgO in the charge to 2·0–2·5% above normal and addition of limestone and dolomite in the proportion of 1:1 had practically no effect on the hardness of the sinter but a further increase of MgO beyond this limit reduces its quality. Constant MgO can be ensured by mixing limestone and dolomite in the ore yard.

Production and use of fluxed sinter with a basicity CaO:SiO_2 of 1·2–1·4 F. F. Kolesanov (*Stal'*, 1960, (7), 593) A note from Chelyabinsk. Up to 56% in the blast-furnace burden reduces coke consumption 4·3% and increases productivity 3·2%.

Elementary notes for a study on the Sturzelberger process F. de P. Giménez Blasco (*Hierro y Acero*, 1960, **13,** Jan.–March, 242–245) The reduction of iron pyrites by the Sturzelberger process is briefly described.—S.H.-S.

FUEL—PREPARATION, PROPERTIES, AND USES

Activities of the Commission des Ingénieurs de Cokeries M. Duvivier (*Rev. Mét.*, 1960, **57,** April, 287–296) The possibilities of increasing the production of metallurgical coke in France are examined, reference being made to the production of coke fines for sintering plants, and to the improvement of thermal efficiency and other factors in coke-oven operation.

Use of PS coal in sinter production V. M. Malinovskii and A. S. Babii (*Stal'*, 1960, 7), 593) A note from Enakievo. Up to 25% PS coal had little effect on rate or quality but above 50% yield fell 5·4%, the rate increased slightly and FeO was decreased. **Sinter tests with addition of mill scale** The optimum content was 10%. 20% reduced productivity 9·4%.

Laws governing the heating of hard coals in the coke oven M. Pustal (*Bergakademie*, 1960, **12,** Jan., 33–35) A review (6 refs).

Quality of metallurgical cokes. Metallurgical raw materials C. G. Thibaut (*Cahiers du Cessid*, 1959, (XII supplement), pp.32) Physical, mechanical, and chemical properties of cokes are discussed in relation to their metallurgical applications. Results of tests carried out on cokes of different origin are compared as well as results obtained in various countries (79 refs).—R.P.

Durgapur makes steel: Coal–coke–power (*Brit. Steel.*, 1960, **26,** May, 151–152) The coal preparation, coke and by-products plants and distribution system are described briefly, with reference to the works power station.

TEMPERATURE MEASUREMENT AND CONTROL

Temperature measurement and control. I. Thermocouples E. W. Jackson (*Chem. Process Eng.*, 1960, **41,** April, 139–143) The principles of thermo-electricity, the selection of thermocouple elements, compensation, and installation and maintenance of thermocouples are reviewed. **II. Temperature control data logging equipment** W. J. A. Donnelly (144–145, 148) A system for temp. monitoring and data logging for a continuous chemical process plant is described. Information is derived from 440 thermocouples, all within the range 0–300°C. The thermocouples are scanned every 15 min; the value of each point is compared with preset upper and lower limits and any deviation is printed out, if necessary an alarm is raised.

The total radiation pyrometer, the immersion thermocouple and the measurement of converter temperatures I. Harveng and J. Marot (*Silicates Ind.*, 1960, **25,** May, 235–242) The development and use of a Ni–NiCr thermopile, embodied in a total radiation pyrometer, for the continuous recording of bath temp. in a static basic Bessemer converter are described. Maintenance and precautions necessary in using the instrument are discussed. At 1560–1670°C, temp. was read with an estimated error of ±18°C.—P.F.

Temperature measurement in steel melts with a new type of immersion thermocouple H. J. Meerkamp van Embden (*Giesserei*, 1960, **47,** June 16, 328–329) The thermocouple is

made by drawing down to about 2 mm a nickel tube containing a Pt–Pt/Rh couple insulated with MgO. The instrument has a low heat capacity, can be used again after cutting off the end, and is sufficiently flexible to be coiled. Some applications of the thermocouple are outlined.

REFRACTORY MATERIALS

Refractories D. Dixon (*Found. Trade J.*, 1960, **108,** May 5, 545–550) A review of the properties and uses of refractories, particularly with respect to the enamelling industry. The selection of refractories for enamel-frit melting is described and the properties and suitability of the various fusing furnaces are discussed.

Study of the composition of siliceous refractories F. M. del Corral and J. M. Bermudez de Castro (*Hierro y Acero*, 1960, **13,** Feb., 159–168) The compositions of five siliceous refractories are examined by means of X-ray diffraction and they are compared with their relevant microradiographs and photomicrographs.

Economies in the use of refractories K. W. Hansen (*Blast Furn. Steel Plant*, 1960, **48,** June, 567–568) Particular reference is made to specialized refractories for use at high temp. and under severe operating conditions, and to the use of monolithic linings.

IRON AND STEEL, GENERAL

The world's producers of stainless steel (*Met. Bull.*, 1960, July, 78–85) A list of all producers of stainless steel in the world except those behind the iron curtain, giving addresses and the products ranging from ingots to wire.

The French stainless steel industry M. Maroy (*Met. Bull.*, 1960, July, 53–60) A survey of the French production of stainless steel and some of its applications.—T.G.

Progress in Sweden E. Öhmann (*Met. Bull.*, 1960, July, 67–69) An economic survey of the rise of the Swedish stainless steel production which amounts at present to 19 kg per capita, it is expected that this figure will have risen to 25 kg by 1962, by far the highest in the world.

Growing production in Italy Associazione Industrie Siderurgiche Italiane (*Met. Bull.*, 1960, 70–71) A statistical survey of the increasing production of stainless in Italy.—T.G.

A vigorous Japanese Industry Japan Iron & Steel Federation (*Met. Bull.*, 1960, July, 63–65) The structure of the Japanese stainless steel producing industry is briefly outlined.

Durgapur makes steel, 1956–1960 (*Brit. Steel.*, 1960, **26,** May, 147–148) The 13 companies forming the consortium of Indian Steelworks Construction Co. are enumerated, and the construction programme outlined.

New ways of intensifying metallurgical processes I. P. Bardin (*Metallurg.*, 1960, (1), 4–6) The increase in the technical and economic indices attainable by new construction is cancelled out by the expenditure in extra repairs, maintenance, etc. New ways have to be found either by modernizing existing plant or by constructing new plants to attain more intensive production. Rolling combined with continuous casting is to be developed, blast-furnaces of over 2000 m^3 capacity, OH furnaces of between 600–1000 t, improvement in the quality of sinter so as to obtain concentrates with 60–65% iron content, and production of pig iron in blast-furnaces with oxygen blast etc.

New successes for the day of the metallurgist P. I. Korobov (*Stal'*, 1960, (7), 575–578) A review of achievements during the year to be reported on the occasion of the metallurgists' Labour Day festival, giving a list of new plants, improved operations, and output.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Durgapur makes steel—The ironworks (*Brit. Steel*, 1960, **26,** May, 153, 161) By 1961 three blast-furnaces will be in commission, and it is intended to make 2500 t of basic pig and 1250 t of foundry iron per day. Design data are given.

Achievements of blast furnace production in the Chinese People's Republic (*Metallurg.*, 1960, (4), 9–13) A review of the growth of the industry during the last decade. The data are condensed from an article in the Chinese periodical *Steel and Iron*, 1959, (18).

The operation of a blast furnace of 1700 m^3 volume at Espérance-Longdoz, Liége P. Maertens, J. Cobut, U. Delince, P. de Woot, and A. Herman (*Rev. Univ. Min.*, 1960, **103,** June, 272–294) In the first part the authors describe the details of the construction and ancillary equipment of No.6 furnace, with 8·75 m hearth diameter, put into operation at Espérance-Longdoz in April 1959. In the second part the results obtained in the furnace are discussed in detail, working at a top pressure from 600 to more than 1000 g/cm^2 (12 refs).

Towards international standardization of reports on blast-furnace trials C. G. Thibaut (*Rev. Mét.*, 1960, **57,** May 379–386) Proposals are made for standardized tabulation of results with the aim of simplifying interpretation of furnace and burden characteristics. An example from practice is given.

Blast-furnace smelting of lead-bearing iron ores A. M. Sukhachev (*Stal'* 1960, (7), 590–593) Rumanian and Bulgarian blast-furnace smelting of local ores are described. Lead recovery and hygienic conditions during casting are attained. Attack on the refractories is observed. Lead can be discharged by means of channels in the hearth pad lining.

The effect of the grading of the burden on the operative indices of blast furnaces V. E. Levchenko (*Izvest. VUZ Chern. Met.*, 1959, (11), 19–22) The particle size of the burden components can in most cases be improved with an increase in gas permeability and a fuel saving up to, in certain cases, 11%. A higher pressure of the gases in the working space is also desirable.

The kinetics of sulphur transfer from iron to slag R. G. Ward and K. A. Salmon (*JISI*, 1960, **196,** Dec., 393–403) [This issue].

Blast furnace studies. Heat balance sheet and heat exchange J. Michard (*Cahiers du Cessid*, 1959, No.49, pp.127) Thermal flow and heat exchange in various parts of the blast-furnace are discussed from theoretical and practical points of view. The relationships between heat exchange and reduction processes in the furnace are dealt with (17 refs).—R.P.

Inwall thermo-couples guide to better blast furnace operation J. S. Kapitan (*Blast Furn. Steel Plant*, 1960, **48,** June, 561–566) The use of in-wall thermocouples as an indication of gas flow efficiency, the presence of hot spots, etc. is discussed. The effect of sized ore: sinter, steam, and high-pressure on inwall temp. ranges are examined.

The operation of air heaters with variable cycles G. V. Ilyushchenko and M. G. Volkov (*Metallurg.*, 1960, (4), 4–8) When the blast-furnaces were enlarged at the Kuznetsk Metallurgical Combine the air heaters were increased in volume and operated at a higher temp. and pressure of air blast. Checkers were increased in height and reconstructed to reduce the dimensions of the vertical flues. A complete automation scheme of control was introduced and this has resulted in increased efficiency.

Tapping the pig iron through one spout I. I. Morev, N. I. Savichev, N. G. Tubenko, A. I. Khabarova, N. S. Krivolapov, V. M. Zudin, and L. Ya. Shparber (*Metallurg.*, 1960, (2), 12) A group of engineers at the Magnitogorsk Metallurgical Combine have evolved a pouring device consisting of a platform with a mobile runner which can be rotated by a winch. A diagram is supplied.

Improvement of some devices for the automatic control of blast furnaces N. S. Skorik (*Metallurg.*, 1960, (2), 9–12) Description of some devices now available for temp. measurements of the hot gases and of the gases at the periphery and under the top; also for controlling the valves of the large and small cones, of devices for controlling gas pressures, humidity, etc.

Manufacture of pig irons in blast furnaces for producing nodular graphite iron and properties of the castings I. Aoki (*Hierro y Acero*, 1960, **13,** April, 365–370) Anomalies arising from the manufacture of pig iron in the blast-furnaces of the Kamaishi plant are described, with results requiring the use of a superior class of material for the production of satisfactory nodular graphite iron.—S.H.-S.

Proposed schemes of gas purification units for metallurgical works P. S. Khomutinnikov and Yu. M. Dronevich (*Stal'*, 1960, (7), 660–664) Electrostatic filters for blast-furnace plants and other devices, especially for operation with high top pressures, and installations for OH furnaces and O_2-blown converters are briefly reviewed.

Purification of blast-furnace gas without electrostatic filters D. K. Myzenko, V. M. Ponazuev, M. S. Mironchik, and L. Yu. Korol'kevich (*Stal'*, 1960, (7), 667–670) Tests on gases from furnaces operating at high top pressures show that water-sprinkled baffle units can reduce dust content to 10 mg/m^3.

Properties of blast-furnace dust and its collection in the gas purification apparatus P. I. Vernigor (*Stal'*, 1960, (7), 664–667) Sedimentation patterns in scrubber and baffle units and the effects of flow rate and pressure drop are examined. With high flow velocities, electrostatic purification is not needed. Particle size distributions are determined and related to rate and position of collection.

Techniques of pig-iron production J. Taylor (*Found. Trade J.*, 1960, **108,** May 19, 615–619) This is a summary of a review on alternatives to the blast-furnace as a reduction unit, presented to a meeting of the West of Scotland ISI.—T.G.

Production of sponge iron from compact hematite and its fusion in a Detroit laboratory furnace T. D. de Souza Santos (*Bol. Ass. Bras. Met.*, 1960, **16,** April, 233–242) A report on a series of laboratory tests made at a steel plant at São Paulo and presented to the XIV Annual Congress of the Brazilian Association of Metals is here reproduced.—S.H.-S.

Production of sponge iron by the Hoganas process with coal from Rio Grande lo Sul, hematites from Minas Geraes and eucalyptus charcoal Y. Wahlberg and A. C. Lopes (*Bol. ABM*, 1960, **16,** April, 219–232) With a view to rectifying the inbalance of commercial production of sponge iron in Brazil with prime raw materials of Brazilian origin and production, a series of tests undertaken in Sweden by the Hoganas A–B process is briefly described and covers each product.—S.H.-S.

Production of iron and steel by electric processes H. Walde (*Hierro y Acero*, 1960, **13,** Feb., 218–228) After discussing the operation of the Ens electric furnace for cast iron, the problem of a process in course of development for the treatment of fine minerals from, e.g. Sweden, Brazil, and Venezuela, is mentioned, passing on to the idea of a purely electric plant, in which the iron obtained in the electric reduction furnace is converted into steel in the electric arc furnace by the von Roll process.

New processes of desulphuration of pig iron outside the blast furnace S. K. Sobolev, G. N. Oiks, V. F. Isupov, and V. M. Smetanin (*Izvest. VUZ Chern. Met.*, 1959, (11), 13–18) A method is explained of desulphurizing pig iron by bringing it in turbulent contact with a desulphurization agent consisting of 1·5–2·8% lime mixed with 0·03–0·06%Al. This removes 30–60% of the sulphur in the pig iron. The agent is added as a suspension of air when it is more effective.

Desulphurization of the pig iron outside the blast furnace L. Ya. Shparber (*Metallurg.*, 1960, (2), 8–9) An arrangement is described for desulphurizing pig iron as it flows through the tundish. The agent consists of the waste of calcined lime and dolomite. The average degree of desulphurization obtained is 28·6% with a consumption of lime at the rate of 1·42% by weight of the pig iron.

Gazal for iron desulphurization (*J. Met.*, 1960, **12,** March, 231) An abstract of a report by Société des Acieries de Pompey on successful trials with the Gazal process, by which air or N_2 is introduced through a porous refractory plug in the ladle bottom, to produce turbulence and thereby promote slag–metal reections.

Rotary reactor desulphurizes and desiliconizes (*J. Met.*, 1960, **12,** March, 232–233) A description of the design, operation, and applications of the rotary reactor designed by Diamond Alkali Co. Development work has still to be carried out on the use of the reactor for dephosphorization, decarburization, and direct reduction.

PROPERTIES, TREATMENT, AND USE OF SLAGS

Laboratory experiments on the use of apatite for enriching Talbot slags with phosphorus pentoxide T. Myslivec and V. Černý (*Hutn. Listy*, 1960, **25,** (3), 188–195) Experiments showed that Talbot slags unsuitable for agricultural purposes can be converted to basic Bessemer type slags rich in P_2O_5 by melting with apatite. The best method consists in throwing apatite, sand, and basifrite on to the slag before the latter is drawn off.—P.F.

The production of basic Bessemer slags by the Talbot process O. Bohuš (*Hutn. Listy*, 1960 **15,** (4), 292–295) Present-day economic conditions favour the use of comparatively low-P irons together with apatite in the Talbot process in Czechoslovakia. Agriculturally useful slags are thus obtainable. The chemical and economic aspects of the method are discussed.—P.F.

Apparatus for measuring the surface tension of slags in steel melting furnaces L. I. Rostovtsev (*Zavods. Lab.*, 1960, (3), 351–353) The instrument is used to determine the properties of the slag in OH furnaces during the progress of the melt. It is simple in construction and operation and the readings are independent of the depth of immersion of the capillaries, which is very important in a boiling bath. The apparatus consists of three sections, a high temp., a controlling, and a recording section. The main section, the first, consists principally of a bent iron tube with graphite ends through which pass two copper tubes, hermetically sealed to graphite capillaries containing thermocouples. The portion of the iron tube which is immersed in the bath is lined with a refractory coating. Equations are given for calculating surface tensions from the readings of the two capillaries simultaneously immersed in the liquid bath.

Apparatus for measuring the viscosity of slags L. Georgiev, M. Mandl, and I. Skala (*Zavods. Lab.*, 1960, (3), 358–360) The apparatus consists of a frame through which passes a shaft driven by an electric motor. The end of the shaft rotates in a crucible furnace containing molten slag. Resistance to rotation gives the viscosity after suitable calculations. The apparatus has been calibrated on castor oil and fused B_2O_3. It can register viscosities of 0·4–20 and 10 to 100 poises.

Standards for measuring the viscosity of metallurgical slags O. M. Katkov (*Zavods Lab.*, 1960, (3), 360–361) Results of tests over a long period with standards consisting of castor oil (Standard No.1) and its mixtures with rosin in the proportions of 3:1; 3:2; and 1:1 (standards No.2, 3, and 4) are reported. Viscosity is determined by the fall of a ball and is assessed by the Stokes equation, with corrections for the size of the container.

The reactive capacity of blast furnace slags for sulphated metallurgical cement S. Tsumura (**Zement–Kalk–Gips*, 1959, Sept., 392–408) Slag reactive capacity is investigated using a solution of gypsum, and a relation is derived between reactive capacity with SO_3 and the modulus of elasticity of sulphated cement made from the same slag. Slag properties are investigated on synthetic slags (20 refs).

PRODUCTION OF STEEL

Durgapur makes steel—tonnage oxygen plant (*Brit. Steel.*, 1960, May, 149–172) The tonnage oxygen plants supplied by British Oxygen Linde Ltd. are described. The oxygen is used mainly for ladle desiliconization.

Oxygen enrichment in a crucible furnace T. C. Churcher and C. A. Walters (*Found. Trade J.*, 1960, **108,** Feb. 18, 191–194) The addition of 2% and 4·5% O_2 to the air supply of an oil-fired crucible furnace gave no marked increase in the wear of either the crucible or the furnace lining. No apparent difference was found between the two levels of O_2 enrichment, both of which permitted reduction of melting times and fuel consumption of about 12%.

Lining low-frequency crucible-type furnaces S. Fransson (*Gjuteriet*, 1960, **50,** (6–7), 87–94) Post-packing of rammed quartzite linings due to vibrations in the furnace coil and crucible has been reduced or eliminated by correct grain size and distribution, ensuring that the material is dry when rammed, and modifications to the ramming technique.

Contribution to the mechanics and metallurgy of the blowing process T. Kootz (*Bergakademie*, 1960, **12,** Jan., 16–22) The course of refining in OH and converter processes is compared, and the mechanism of refining by bottom-blowing and by top-blowing with O_2 are discussed (23 refs).

The Bessemer converter and the problem of the shortage of scrap steel J. Vazquez Lopez (*Hierro y Acero*, 1960, **13,** April, 437–457) To overcome the phenomenon of a growing shortage of scrap steel in Spain, the author advocates a cyclic system of blast-furnaces feeding 40% of liquid cast iron to OH furnaces, to be admixed with their own charge of 25% scrap, with a further addition of 35% native ores, smelted in duplex, as a process which he claims to be, in Spain, both economically possible and convenient.—S.H.-S.

Temperature measurements in the Bessemer converter K. S. Garger, N. T. Bondarev, B. V. Lvaudis, and D. P. Ul'yanov (*Izvest. VUZ Chern. Met.*, 1959, (11), 125–132) A pyrometer has been designed and constructed to be used with standard thermo-electrical devices, fixed on a water-cooled tube with a reciprocating motion. This instrument, used in the mouth of a Bessemer converter blown from the bottom with air blast has proved its reliability.

Investigating the contamination of converter steel-top blown with oxygen V. I. Baptizmanskii and Yu. A. Dubrovskii (*Izvest. VUZ Chern. Met.*, 1959, (11), 31–37) Certain recommendations are made to decrease oxide inclusions in the production of VKD steel (oxygen top-blown): normal melt as regards temp.; holding the blown metal in the converter for a certain time; drawing off the slag midway through the melt; adjusting the lance during the melt.

Plant for the manufacture of steel by the L.D. process A. Alvarez Alvarez and F. D. Bustamante (*Anal. Mec. Elect.*, 1959, **36,** Nov.–Dec., 452–463) A technical study of the layout, equipment, and process for the production of steel by the Linde–Fränkl system.

End-point temperature control in LD steelmaking W. J. Slatosky (*J. Met.*, 1960, **12,** March, 226–230) A slide-rule type of computer, based on a set of equations derived from a thermochemical analysis of the LD process, is in use at the Jones and Laughlin Aliquippa works for controlling end-point temp. An electronic computer is to be installed for greater accuracy and ease of operation. The equations used and results obtained are quoted.

Report on the metallurgical conference in Belgium and Luxembourg in 1958 G. Répási (*Koh. Lapok*, 1959, **14,** Sept., 393–397; Oct., 477–482) The author reviews the lectures on steelmaking heard at the international metallurgical conferences in Belgium and Luxembourg in 1958, and draws some conclusions relevant for the Hungarian steel industry.

Steelmaking at Paraná P. A. Nowlands (*Eng. Min. e Met.*, 1960, **31,** Jan., 10–12) [In Portuguese] The author discusses the possibilities of building iron and steelmaking plant at Paraná to take advantage of the ore deposits there. Raw material and transport requirements are considered.—P.S.

Tonnage oxygen through low pressure process A. Urban and V. Anděl (*Czech. Heavy Ind.*, 1960, (6), 40–46) A general description.

The central oxygen plant at Richemont (*Mines Mét.*, 1960, June, 357) A brief account of the opening of the central depot supplying 2400 l/h of liquid and 150 t/day of gaseous O_2, with sketch map of the distributing area.

The basic oxygen process in a modern American steelworks L. Walter (*Chal. et Ind.*, 1960, **41,** May, 140–144) This article describes the operation and economics of the basic oxygen process at the Aliquippa works of Jones and Laughlin Inc. in Pennsylvania.

Increase of production of basic Bessemer steel by the use of oxygen G. de Rousiers (*Centre Doc. Sidér. Circ.*, 1960, (2), 469–473) A study of the effects of the use of O_2 in diminishing the time of blast and increasing production of a basic Bessemer steel plant by 10–15% and giving greater flexibility of operation is reported.—S.H.-S.

Continuous determination of the bath temperature during Thomas conversion I. Harveng, J. Hancart, and J. Marot (*Rev. Mét.*, 1960, **57,** Jan., 221–238) Temp. changes during air-blowing are followed by the use of an Ni–Cr/Constantan thermopile sighted on to the bath through the converter mouth. Details of the recordings in relation to the reactions in the converter are examined, and the possibility of correcting the temp. at an early stage of the blow is considered.

Refractories for the L–D Converter H. P. Guimarães (*Bol. ABM.*, 1960, **16,** Jan., 83–96) A brief description of the refractory linings and consumption of the L–D furnaces is given. Refractory importance is measured by its cost per ingot t and plant availability, the difficult conditions are caused by the high temp. and the fluidity and activity of the slags. It is concluded that the destructive factors will be minimized by the use of basic materials with high indices of refractoriness, made with particular attention to producing low porosity and a high thermal shock resistance.—P.S.

Non-combustion recuperation of the gas obtained from refining with pure oxygen (CAFL and IRSID processes) M. Allard and G. Namy (*Rev. Mét.*, 1960, **57,** March, 207–220) Tests made on a 5-t converter have shown the possibility of removing the high-calorific CO-rich gases produced in the CAFL and IRSID processes. Collection of these gases would result in considerable economies in dust-removal plant.

Investigations of productivity in basic open-hearth furnaces O. L. Barbosa and L. V. da Silva (*Bol. ABM.*, 1960, **16,** Jan., 21–38) Evidence is given to show the advantages of using statistical analysis for the diagnosis and solution of production problems as well as for production control. The basic OH plant of CSN at Volta Redonda is considered and the effect of certain variables upon the heat time is examined. Conclusions which apply to this shop are: (i) a variation of the charging time of the solid charge is reflected in a variation of the same order in the heat time; (ii) increasing the proportion of liquid iron in the charge would have economic advantages; (iii) the control of bath carbon is important for the reduction and control of heat time; (iv) by control of the metal charge and the quantities of raw materials charged a greater use of plant capacity is possible; (v) production control can be effected, with advantage, by using Shewhart charts (10 refs).—P.S.

Strength calculations for open-hearth furnace elements N. P. Kublanov (*Stal'*, 1960, (6), 500–502) Defects in equations commonly suggested for roof thrust, etc., especially in A. S. Lychagin's book, are pointed out and the need for a special guide for designers is stressed.

Development of an open-hearth furnace with a new profile E. Boelens (*Radex Rund.*, 1960, April, (2), 71–85) The results obtained with the new design introduced in a Liège steelworks in 1952 are reviewed, with an account of design modifications, and the Maerz–Boelens all-basic furnaces are described, with an account of the suspended roof and wall structures.

Progress in the use of oxygen in the open-hearth furnace M. Foresi and G. Massobrio (*Radex Rund.*, 1960, Feb., (1), 3–38) [In German and Italian] Developments in the use of O_2 in the OH plant of Cornigliano S.P.A. are described, using various methods of feeding the O_2, by tubes through the furnace doors, O_2 lancing through the roof, and O_2 enrichment of the fuel through the burners. Trials with silica and with basic roofs are described, and conditions necessary for plant modification for the large-scale use of O_2 are discussed.

Open-hearth furnace door-frames E. Poulain (*Centre Doc. Sidér. Circ.*, 1960, (2), 487–494) Seven types of water-cooled frames are described and their construction and functions are discussed.—S.H.-S.

Basic roof performance in American open-hearth furnaces M. A. Fay (*Blast Furn. Steel Plant*, 1960, **48,** April, 372–376, 386–387) Data from 233 basic roof campaigns completed since 1947 have been studied, and performance results are analysed.

Influence of the furnace lining on the course of the melt in the acid open hearth process H. Widmark (*Jernkont. Ann.*, 1960, **144,** (1), 1–45)

Steel and slag samples were taken during the refining period on four heats and bottom wear and amount of slag were measured by radioactive tracers. In addition, the results of oxygen determination with different methods of sampling were compared. The activities of the components in the slag and steel were determined, and used for equilibrium calculations (45 refs).

Introduction of blown air into gas ports to intensify the melting process V. N. Kazantsev (*Stal'*, 1960, (6), 504) Discussion of an article with the same title by I. V. Belov *et al.*, (1959, (10), 889). Air velocity, which was not discussed in the article, is claimed to be the main factor. High pressures are recommended.

Melting of 25GS steel in open-hearth furnaces V. G. Malinovskii and A. S. Babii (*Stal'*, 1960, (6), 513) A note from Enakievo.

Some questions on the theory of the dephosphorization process I. Yu. Kozhevnikov (*Stal'*, 1960, (5), 406–416) The sequence of oxidation of impurities is considered and the conditions for preferential oxidation of P. The order derived from heat of reaction and oxide stability would be Si, Mn, C, P, but this is not observed and other factors must be concerned. The analysis by Levin is shown but the oxygen activities assumed are not usually reached and there is also a solubility effect of the oxides produced. Other formulations are mentioned. Actual P equilibria in slags are considered. It is shown that the important reactions occur at the slag-metal interface.

The production of steel by the duplex process from naturally alloyed Cr–Ni pig irons I. N. Varnavskii, N. P. Izotov, M. K. Musikhina, V. A. Aver'yanov, and O. P. Bolotov (*Stal'*, 1960, (6), 496–500) A process used at Orsk–Khalilovo with a converter and a basic OH furnace is described. The irons are high in Cr, Si, and P. Conditions for the blow are given and slag compositions are shown. The molten metal is conveyed from the converter to the OH in ladles. Rimming and killed steel are produced by processes given. Dephosphorization processes are still being improved.

A change from open-hearth to arc electric furnaces W. J. Bolton (*Blast Furn. Steel Plant*, 1960, **48,** April, 350–356) The modernized plant installed at the Seattle plant of Bethlehem Steel Co. is described; it consists of two 100-t electric arc furnaces, ancillary equipment, and rolling mills.

Electric reduction—oxygen steelmaking v. sponge iron—electric steelmaking A. C. Lopes (*Eng. Min. e Met.*, 1959, **29,** June, 323–324) [In Portuguese] The advantages and disadvantages of each of these methods of steelmaking are tabulated and compared. The equipment needed and raw material consumption per ton are listed and investment costs are given.—P. S.

Possibilities offered by the O.L.P. process for the manufacture of dead-mild rimming steels for deep drawing J. Samson and G. Montlahuc (*Rev. Mét.*, 1960, **57,** May, 387–395) Based on the results obtained from 250 heats, it is shown that the quality of OLP steel is better than that of OH steel, particularly for deep-drawing purposes. The mechanical and chemical properties of the steel are discussed and the results of cold and hot-rolling trials are examined statistically.

Durgapur makes steel—Open hearth melting shop (*Brit. Steel.*, 1960, **26,** May, 155–156, 159–161) The design, equipment, and capacity of the plant are described. The furnaces, consisting of seven 200-t and one 100-t fixed basic furnaces, are designed for 80% hot metal and 20% scrap.

Construction of OH furnace shops with furnaces placed in island blocks I. D. Vikhrev and I. A. Afonin (*Metallurg.*, 1960, (1), 18–22) A project submitted by Gipromez demonstrates than an arrangement of furnaces in island blocks instead of in long lines results in appreciable advantages.

Conclusions to be drawn from recent investigations on the planning of open hearth furnaces G. Husson (*Rev. Mét.*, 1960, **57,** May, 401–407) A general review of papers presented at an Open Hearth Conference, dealing with measuring instruments, general conditions of thermal exchange, the case of a furnace fired with cold rich gas, and preheated lean gas respectively, the influence of the flame on the furnace geometry, and the use of oxygen.

The correct roof thickness of OH furnaces I. I. Nemets and V. A. Makovskii (*Izvest. VUZ Chern. Met.*, 1959, (11), 119–124) Methods for calculating the required thickness of the roof have been evolved at the 'Azovstal' works, based on campaigns with the 350-t tilting OH furnaces. The results have been confirmed by actual trial and have made possible the formulation of a relation between the temp. of the external surface of the roof and the thickness of the brick lining with a constant temp. of the working space of the furnace of 1750°. In this way the roof thickness can always be kept at 380 mm as the campaign proceeds, with a considerable saving in refractories.

Increasing the service life of basic roofs and checkers E. D. Akol'tsev and V. B. Kaplun (*Metallurg.*, 1960, (1), 14–16) The low service life of basic roofs is due to spalling during hot repairs; between 30 and 60 mm crumble each time the temp. drops to 900°. This is due to the expansion of the brick saturated with iron oxides, the concentration of which rapidly increases at the expense of MgO which diminishes. As a first preventive measure the roof is heated during hot repairs. For this purpose a burner has been constructed of a capacity of 1500–1800 m^3/h which works with compressed air at a pressure of about 4 atm. Regarding checkers a special construction is proposed for the checkers of dinas chromite and magnesite chromite bricks.

Service life of OH furnace roofs N. N. Kirillova and Yu. V. Radina (*Metallurg.*, 1960, (4), 17–20) A summary of the general position regarding magnesite–chromite roofs which at the beginning of 1959 were used in over 90% of the OH furnaces and were responsible for over 96% of the steel melted. The conditions of service and the various improvements introduced in a number of plants are reported.

Shortening fettling times of furnace hearths M. R. Shelovanov and I. A. Vasserman (*Metallurg.*, 1960, (1), 22–23) A new method of fettling the hearth after main repairs is indicated with a special slag of 10–40 mm grain size laid down in layers melted on separately. The total time for a 240 mm thick layer is 35½ h. Such 'prophylactic' repairs are carried out at the Uzbek Metallurgical Works after every 60 heats.

Use of manganese ores in the scrap process when working on low manganese pig iron Yu. A. Kamenskii (*Metallurg.*, 1960, (1), 16–18) Results from experimental melts have shown than an increase of manganous oxide in the slag by charging in the OH furnace a proportion of 1·0–1·5% manganese ore on the weight of the total charge is a very effective means of desulphurization of the metal. When cold low-Mn pig iron is used, Mn ore can also be added in the finishing period, when an increase in the Mn content in the metal is accompanied by a reduction in the sulphur content. The use of this ore also considerably reduces the consumption of Fe–Mn in the deoxidation of steel.

Use of iron from the hot-blast cupola in the open-hearth furnace D. Rabe (*Stahl Eisen*, 1960, **80,** Aug. 4, 1083–1084) An OH works that did not make use of a liquid charge, built a hot-blast cupola for providing the necessary quantities of liquid iron. It was found that all-round savings were made when about 40% liquid iron was charged to the OH furnaces.

Improvement in the productivity of an open hearth furnace of 70–80 tons capacity fired with rich gas and tar A. le Moyne (*Rev. Mét.*, 1960, **57,** May, 409–422) The characteristics are described of the 70–80 t Maertz furnace at the Thionville steelworks of the Société Lorraine-Escaut, and the results of trials firing with various flame strengths and using coke oven gas with and without tar additions are reported.

Direction and practical results of research carried out recently in France with the aim of improving open hearth firing conditions L. Septier, M. Rivière, and G. Husson (*Rev. Mét.*, 1960, **57,** April, 303–310) The results of research over the past 10 years are reviewed; they include increasing the reaction impetus at the burners; improvement of heat transfer by increasing radiating power of transparent flames; carburation with a liquid fuel or pure oxygen, use of multiple burners traversing the arch; and control of the rate of oxidation of the charge during melting down.

Use of cold gaseous fuel for firing open hearth furnaces G. Decamps (*Rev. Mét.*, 1960 **57,** May, 397–400) The type of fuel, burner design, and flame control are outlined, and it is shown that an increase in production of at least 6% is obtained in the manufacture of dead-mild steel by using an excess pressure of 1 kg at the burner. The effects on iron oxidation of atomizing with air or steam are reported.

The concept of quantity of movement at the burner and the firing of the open hearth furnace M. Rivière (*Rev. Mét.*, 1960, **57,** April, 297–301) Characteristics of free jets and the effect of combustion on these characteristics are examined, and the influence of enclosure on a flame jet is studied. The conception of 'quantity of movement' and of intensity of combustion in OH furnaces fired with pre-heated lean and rich fuels is investigated.

The melting of high quality steel in natural gas fired open hearth furnaces V. A. Kudrin, G. N. Oiks, S. P. Sorokin, Yu. M. Nechkin, M. V. Glushtsov, B. P. Nam, M. P. Lapshova, A. A. Yudson, O. D. Petrenko, and V. P. Adrianova (*Stal'*, 1960, (7), 599–602) The change in heating conditions and in furnace atmosphere in natural gas firing requires changes in practice. These factors, especially flame structure and the influence of frothing in the slag, are discussed, overheating of roof and checkers is also encountered.

The effect of the type of the kinetic process of decarburization on the content of hydrogen, oxygen and nitrogen in the metal O. D. Zorin (*Izvest. VUZ Chern. Met.*, 1959, (11), 39–41) Three types of kinetic processes of decarburization are distinguished according as the rate of decarburization is constant (Type I), decreases (II), or increases (III). The factor considerably influencing the H_2 concentration during the boil is the rate of decarburization. The excess of O_2 in the metal above the equilibrium concentration with carbon is greater by a factor of 1·5 in Type I kinetics than in Type III. The N_2 content in the metal does not depend on the kinetics of the process.

The refining of alloy steels with liquid synthetic slags S. G. Voinov, A. V. Korneenkov, A. K. Petrov, Ya. M. Bokshitskii, A. I. Markelov, A. G. Shalimov, L. F. Kosoi, O. M. Chekhomov, and G. A. Khasin (*Stal'*, 1960, (7), 611–618) Trial heats of ball-bearing, structural and stainless steels in basic arc furnaces were treated in the ladle with synthetic slags prepared in a 10-t arc furnace. The construction of this furnace is described. This process increases steel quality and much improves output. S is reduced and mechanical properties are improved.

Improving the desulphurization during the melting of high carbon steels V. G. Kravtsov and B. A. Rogulev (*Metallurg.*, 1960, (2), 17–18) The new method is based on a charge consisting of 60% liquid iron and 40% scrap. 11–12% limestone and 2% bauxite are added to the charge depending on the chemical composition of the iron. This ensures, at the end of the melt, a highly basic liquid slag with excess CaO, which is necessary to obtain good desulphurization at the moment of deoxidation, when sulphur content falls to 0·02%.

The behaviour of phosphorus in the bath of the OH furnace during refining A. I. Stronganov (*Izvest. VUZ Chern. Met.*, 1959, (11), 23–29) The well-known beneficial effect on dephosphorization of a highly basic slag with a large proportion of iron oxides but little MnO, and of a bath with a small Mn content has been experimentally confirmed. It has also been established that the optimum value of FeO increases with increasing basicity of the slag, obviously owing to the increasing concentration of Fe_2O_3 in it. This increases also the fluidity and reactivity of the slag by increasing the ratio $(\%P_2O_5)/[\%P]$ which is taken as the index of dephosphorization.

The distribution of chromium in basic OH furnaces S. Buzila (*Met. si Constr. Masini*, 1960, (1), 37–42) The investigations were carried out in the process of melting 40C10

steel (0·35–0·45%C; 0·50–0·80%Mn; 0·80–1·10%Cr; and 0·17–0·40%Si) on an industrial scale, in the normal way by alloying with Fe–Cr and with recovery of the Cr from the charge. The study was based on the variations of the free energy of oxidation based on relations which can be verified in practice such as $4/3\,Cr+O_2=2/3\,Cr_2O_3$; and $2C+O_2=2CO$. By calculating the free energy from the oxidation reactions of the principal elements in the OH furnace both between 200 and 2000°, the variation in the free energy was obtained. It has been established as a first result that to work with only small oxidation of the Cr, the temp. of the process should be so adjusted that the Mn content increases continuously by regeneration from the slag and not by additions of Fe–Mn. ((2), 107–111) The Cr distribution coefficient increases with O_2 content in the bath according to $\%(Cr)/\%[Cr]=3{\cdot}57\times\%[O]-4{\cdot}01\pm1{\cdot}5$ and falls with the temp. of the bath according to $\%(Cr)/\%[Cr]=-0{\cdot}0504\ t+84{\cdot}4\pm1{\cdot}5$. Bath temp. affects the distribution ratio of Cr both directly and through other factors, for example, an increase in temp. slows down the rate of oxidation of Cr and of Fe etc. The Cr distribution ratio increases with the iron content in the slag and decreases with increasing carbon content in the bath.

Air-cooled stopper for the pouring ladle A. V. Malakha, V. T. Sladkoshteev, A. M. Ofengenden, A. V. Eliosof, I. I. Druzhinin, and Yu. Z. Babaskin (*Metallurg.*, 1960, (4), 21–24) At the OH shop of the STALIN Metallurgical Works, rimming, carbon, killed, and alloy steels are cast uphill into 3·4 t ingots. The ladle capacity is 130–135 t and pouring takes from 1 h 10 min to 1 h 30 min. An air-cooled stopper unit is described suitable for different conditions of pouring through a 55 mm dia. opening.

Flames and furnaces—heat transfer in furnace chamber M. W. Thring (*Iron Steel*, 1960, **33,** March, 119–120) Results of calculations on radiation from the flame and the heat available in it have verified the view of practical steelmakers that the optimum flame in the open-hearth furnace is different at different stages in the melt. The optimum flame conditions for three stages in the heat are discussed.

Improving the organization and control of OH furnaces by means of the flame A. A. Dobrokhotov (*Metallurg.*, 1960, (4), 14–17) The experience relates to the 185 t OH furnaces of the Chelyabinsk Metallurgical Works where the effect of the rate of air flow, of the construction of the uptakes, ports, baffle plates, the proportions of air/gas, etc., were studied for a number of years. A combination of changes in these different factors have resulted in an increase in the yield by 8–12%.

Using the steam from the evaporation cooling system of OH furnaces A. S. Balandin (*Promysh. Energ.*, 1960, (5), 13–16) The low-pressure steam from the evaporation cooling system of OH furnaces may be utilized in full for heating the works. The system of cooling may be simplified and cheapened by installing the waste heat recovery boilers directly at the furnaces and especially by equipping them with pumps.

The use of models in the study of the design of metal recuperators R. Kremer (*Hutn. Listy*, 1960, **25,** (3), 170–178) Experiments with model recuperators designed according to principles of similarity theory are described, and these principles are considered. It is shown that useful indications of desirable features in the design of recuperators can thus be obtained.

Reserves of labour productivity in the OH furnace shop V. M. Abaev (*Metallurg.*, 1960, (1), 23–24) At the Magnitogorsk OH furnace shop No.2, productivity has increased since 1953 from 240·2 to 302·7 t per man. This was secured by a fuller use of the equipment, reconstruction of furnaces, mechanization of the labour-consuming operations, new and improved lining and roof bricks, increase in the capacity of furnaces etc.

Methods and results of psychological work studies in open-hearth practice G. Herrmann and W. Naumann (*Bergakademie*, 1960, **12,** Feb., 57–64) Psychological work studies were carried out on a large number of operations in OH melting, and a statistical analysis is given of the results of various operations such as sulphur removal, and contents of various elements in the finished steel, referred to various members of the furnace team.

Fettling electric furnace hearths P. L. Pirozhenko (*Metallurg.*, 1960, (4), 35) The former method of fettling the 3 t electric furnace (1500 kW transformer) at the 'Azovstal' was changed in 1953. The standard magnesite powder is dried in a gas oven. The grain size is 60–63% 4–7 mm dia. and the remainder under 1 mm. This size permits the filling up of the interstices between grains and promotes the formation of a monolithic mass. The service life now reaches 5000 melts.

Electric smelting on a contract basis [Birlec-Efco (Melting) Ltd] (*Sound. Trade J.*, 1960, **108,** March 10, 301–302) For the first time in Britain, a contract service has been made available for electric smelting and a pilot plant built by Birlec-Efco (Melting) Ltd, is now in operation. Erected primarily to promote the development of electric smelting, a user may find out the behaviour of his ore in such an appliance and the economics of metal extraction from it.—T.G.

Electric smelting on approval—pilot plant at Aldridge [Birlec-Efco (Melting) Ltd] (*Iron Steel*, 1960, **33,** March, 105–106) A description of the Birlefco electric pilot smelting furnace at Aldridge and its uses.

Discussion on the lectures on degassing processes for steel (*Berg. Hüttenmänn. Monatsh.*, 1960, **105,** June, 155–157) Among other items discussed were the economics of the degassing processes, a suggestion to use a mains-frequency induction-heated holding ladle for the circulation degassing process which has the advantage that it agitates the melt, and the effect of Ti in vacuum-treated steels.—T.G.

A study of the production technology of magnetic soft steel L. Kodrle and J. Wozniak (*Hutn. Listy*, 1960, **15,** (4), 253–260) A detailed statistical study was made of the effect of production variables on the quality of magnetic soft steel strip containing 0·01–0·05%C. The grain size was found to affect quality most, and production conditions assuring optimum grain size were established. In 20 in wide strip, vacuum degassing of the melt was found to reduce the O_2 and C contents, but did not affect the N_2 content.—P.F.

The use of NiO in alloying steels I. Fučik and J. Skála (*Hutnik*, 1960, **10,** (3), 115–118) Apart from a slight increase in the coke consumption in making 18/8 steel no deleterious effects were observed on using NiO instead of Ni for alloying. The use of oxide in making steels containing up to 8%Ni is urged as this facilitates significant economies.—P.F.

Improvement in the production of 10G2SD (MK) steel V. M. Bednyakov, M. F. Lepin, and G. A. Chikalenko (*Metallurg.*, 1960, (2), 13–16) Steel of chemical composition <0·12%C, 1·30–1·35%Mn, 0·8–1·1%Si, 0·15–0·30%Cu, and <0·04%, 0·04%, 0·30%, and 0·030%S, P, Cr, Ni respectively. A rather complicated change in the normal process permits a reduction by 10–15 min of the melting time. The use of 45% quality Fe–Si is discouraged. The spots and stratification defects usual with the normal process are eliminated almost completely with the new process.

Norms for designers of ingot moulds E. P. Piu (*Hierro y Acero*, 1960, **13,** Feb., 183–217) A study in three parts describes: (1) the conformation of the moulds with a view to reduction of waste from tensile or superficial cracks; (2) the resistance of moulds relative to the metallographic structure and composition of the casting used; (3) the length of life relative to the system of treatment in the pouring, with insistence upon the importance of preheating, the increase of temp. during and after pouring, the period of storage before use (staling), and the properties of the steel poured and the system of pouring.—J.H.-S.

Manufacture of ingots by the [Brazilian] National Steel Co. (CSN) W. Kryvickyj and H. M. Haydt (*Bol. Ass. Bras. Met.*, 1960, **16,** April, 273–311) A comprehensive description of the manufacture, properties, and characteristics of ingots manufactured at the Volta Redonda plant of CSN is given, and causes of structural alteration and failure are discussed.

Improving the ingot of killed steel of average weight A. N. Lekontsev (*Metallurg.*, 1960, (2), 21–22) The trials made during the last few years at the Chusovsk Metallurgical Works to alter the shape, height, and the height/dia. ratio of the moulds are described which resulted finally in obtaining an ingot of 1700 kg. with a ratio H/D of 4·5 ensuring best steel quality.

Casting of steel. Large cast ingots for forgings—Structure R. Ferry (*Cahiers du Cessid*, 1960, No.50, pp.41) The method and most suitable conditions for casting large ingots are discussed in detail. Defects in large ingots are dealt with, in particular with reference to casting conditions (14 refs).—R.P.

Influencing the mode of cooling of ingot heads by exothermic powders and sleeves L. Šmrha and I. Brodský (*Hutn. Listy*, 1960, **15,** (4), 266–275) Possibilities of achieving controlled solidification of ingot feeder heads are surveyed, and the scope of various methods discussed. The development of exothermic insulating bricks in the Ostrava Steelworks is described. These facilitate reduction of ingot head losses to a minimum in the case of small ingots.—P.F.

The causes of overheating and burning of steel J. Elfmark and L. Toman (*Hutn. Listy*, 1960, **25,** (3), 200–207) Overheating and burning were studied in several structural Cr–Ni steels. The principal cause of both effects is the segregation and eventual liquefaction of S- and P-rich phases at the grain boundaries.—P.F.

New electric melting plant at Round Oak Steel Works W. S. Walker and J. F. Whitfield (*Iron Coal Trades Rev.*, 1960, **180,** April 22, 917–924) Choice of site, layout, the furnaces, and the various ancillary installations are reviewed with plans. Electrical supply, control, and instrumentation are also considered.

Working conditions and efficiency of large arc furnaces for steel melting H. J. Forst (*Elektrowärme*, 1960, **18,** June, 192–196) The electrical working conditions for large arc furnaces are derived and the results of operating a modern 80-t furnace for steel melting from the point of view of power consumption and efficiency are considered.—T.G.

Development of electric arc furnaces in the USSR (a discussion) L. I. Aronov (*Stal'*, 1960, (6), 518–519) Economics of electric heating in the USSR where 7·7% of the steel is made in this way (60% castings and 40% ingots) are discussed. Development of duplex processes and use of O_2 is considered.

Electric steelmaking in India D. P. Chatterjee (*Iron Coal Trades Rev.*, 1960, **180,** April 8, 807–813) Installations, since the first in 1920, furnace design, refractories, high-frequency furnaces, the use of O_2, and comparisons with the OH are reviewed.

Electric reduction furnaces W. S. Emrich (*Bol. ABM*, 1960, **16,** Jan., 97–109) An account of the low shaft furnaces at the Mannesmann plant is given and details of their operation are supplied. It is concluded that the development of this process in Brazil depends essentially on the availability and cost of large quantities of energy. The Mannesmann results in recent years show that the process has marked advantages, particularly in medium-sized plants.—P.S.

Metallurgical study of electric furnaces: physico-chemical preamble G. Grenier (*J. Four. Electr.*, 1960, **65,** March–April, 91–93) A summary, covering various aspects of the operation of electric furnaces, including oxidation of Mn and of Si, decarburization, dephosphorization, and desulphurization, with their attendant formulae.—S.H.-S.

Principles governing the dimensions of electric reduction furnaces M. Morkramer (*J. Four. Electr.*, 1960, **65,** March–April, 61–63) A technical review, in which general principles of resistance heating, with flow of current in the furnace, calculation of useful resistances and of dia. of electrodes are mathematically presented.—S.H.-S.

Considerations of the principles of high intensity feeding of electric reduction furnaces S. Bokszczanin (*J. Four. Electr.*, 1960, **65,** March April, 86–89) A sketch of numerous ideas on the propagation of electric current in the technical literature of different countries, with suggestions for their systematic study and

coordination, together with the use of electronic computers for the solution of complicated calculations.—S.H.-S.

Magnetically soft iron nickel alloys J. Papp (*Koh. Lapok*, 1959, **14,** Oct., 437–441) Hungarian experiments on the production, working and heat-treatment of magnetically soft Fe–Ni alloys such as Permalloy B (45%Ni) and Permalloy C (78·5%Ni, 4%Mo) are reported. The alloys were melted in a 50 kg medium-frequency furnace using argon blast for degassing.—P.K.

Technical and economic steel production indices for O.H. and electric furnaces using silico-chromium M. I. Kolosov (*Stal'*, 1960, (6), 568) Type 20 Si–Cr (17–22½%Cr) but not 40 Si–Cr (38–42%Cr) can be used with advantage in OH furnaces. In electric furnaces type 40 can be used.

The production of steel type St52 L. Schottner (*Koh. Lapok*, 1959, **14,** June, 233–238; July, 302–308) After reviewing the development of St52 on the continent and discussing the influence of rolling temp. on its mechanical properties, the author describes in detail the production of this steel in Ozd, Hungary. The chemical analysis of the casts accepted was as follows: 0·14–0·18%C, 0·40–0·55%Si, 0·95–1·25%Mn, 0·15–0·35%Cu, 0·045%S max., 0·045%P max. The steel in the ladle was treated with 0·50 kg Fe–Ti (Ti 20–25%) plus 0·70 kg Al/t of steel.—P.K.

Improved method of producing St5 semi-killed converter steel V. G. Malinovskii and A. S. Babii (*Stal'*, 1960, (6), 513) A note from Enakievo. A method with Fe–Mn and Fe–Si with adjustment in the mould with Al powder was the best of five tested. **Improved method for deoxidizing killed steel** (513) Fe–Mn in the ladle without previous Fe–Si treatment in the furnace reduces melt time and saves Fe–Mn.

Uses of mischmetal in steels C. Bradaschia (*Bol. ABM*, 1960, **16,** Jan., 71–82) The properties and important applications of mischmetal are reviewed. Those covered by patents are listed separately. Its applications in Brazilian steelworks are described and it is concluded that one of the most important effects is that of producing fine-grain structures (23 refs).

A machine with a new type of centrifugal atomizer for applying ingot mould dressings V. A. Kuznetsov, D. I. Titov, N. V. Ivanov, S. M. Tsekhnovich, A. G. Popkov, E. A. Dobrodeev, A. D. Fainberg, and V. I. Prizemnov (*Stal'*, 1960, (6), 514) A multi-disc centrifugal spraying device for coating dressings internally is shown.

The effects of different ingot mould elements on ingot economics S. M. Bobrovskikh and A. G. Nikolaev (*Stal'*, 1960, (6), 502–504) Remelting of unserviceable moulds and rules for determining the point at which replacement becomes economic on account of the increased amount of dressing needed are discussed, and improved feeder head taper, ingot bottom shape, and weight calibration are also considered.

Comparison of linings of bricked and rammed ladles Y. Jouhaud (*Centre. Doc. Sidér. Circ.*, 1960, (2), 497–501) A report is given on tests for damage undertaken at the Mont-Saint-Martin plant with comparative figures of the use of eight bricked and eight tamped ladles.

Pouring of 5 ton Bessemer steel ingots with jets of 70 mm at pouring orifice ~. Kempe and ~. Papier (*Centre Doc. Sidér. Circ.*, 1960, (2), 477–484) An increase of production by the use of 80 mm jets, in place of 40–45 mm jets using plain, not enriched, air, with an improvement in quality of ingots is described.—S.H.-S.

A comparison of technical and economic production indices in the teeming of rimming steel for cold rolled sheet uphill or from the top A. N. Morozov and M. M. Pischikov (*Stal'*, 1960, (6), 568) Uphill casting gave 3·5 times as many rejects as did top casting.

PRODUCTION OF FERRO-ALLOYS

Production of ferro-nickel from garnierite by reduction before melting T. D. de Souza Santos (*Bol. ABM*, 1960, **16,** Jan., 201–214) The preliminary results of an investigation with the aim of producing Fe–Ni with a high %Ni and low C and Si from garnierite are presented. Although there are large reserves of this mineral in Brazil (the deposits contain of the order of 1·8 to 3·0%Ni and 7 to 15%Fe) only one deposit, at Liberdade, is being worked, and used to produce nickeliferous pig-iron containing about 22%Ni, 2%Si, and 3%C. The pulverized garnierite was briquetted with powdered charcoal and charged with more charcoal into Cr–Fe retorts and reduced at 900°C for 20 h. This follows what is essentially the sponge iron process and the same furnace was used. The product was melted in a 15 kW indirect arc furnace resulting in Fe–Ni containing as little as 0·06% carbon and as much as 52·5% nickel, recovery being better than 90%. The same process was used to produce a matte containing 29·7%Ni, 58·5%Fe, and 11·6%S, with 93·5%Ni recovery, using the pyritic residues from a coal washing plant. Herty fluidity curves for the slags produced showed that they had satisfactory fluidity.

Preparation of electrolytic ferro-chrome (*Nat. Met. Rep. Ann. Rep.*, 1958–59, 10) Acid digestion of ore was studied and new designs for digester and electrolytic cell were produced.

Production of low-carbon ferro-chrome (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 24–25) Preliminary work was carried out.

Production of iron chromium manganese alloy (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 23) An alloy with 50–55%Cr and 30–35%Mn can be produced suitable for production of Ni-free stainless steel.

Manganese and ferro-manganese smelting I. S. Plumtree (*Iron Coal Trades Rev.*, 1960, **180,** May 6, 1021–1032) The ores are listed and the uses of the metal, particularly in steel, are outlined. Blast-furnace production of Fe–Mn is reviewed and something is said on arc furnace production, low-carbon Fe–Mn and its pyrometallurgy, silicon and aluminothermic reduction, and electrolytic methods by ore roasting and leaching in addition.

Recovery of ferro-manganese from Joda electric furnace slag by the tabling method (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 15) High grade concentrates could be obtained from all but two samples which were very low in Mn.

The production of ferro-alloys at the Istebné Plant R. Kubina (*Hutnik*, 1960, **10,** (3), 93–95) [In Slovak] The development of output and productivity in these Czechoslovak works during 1951–9 are surveyed. Recommendations for measures leading to further improvements in profitability and total output are made, including the reconstruction of some units.—P.F.

Ferro-nickel production in Oregon E. E. Coleman and D. N. Vedensky (*J. Met.*, 1960, **12,** March, 197–201) A description of the plant of Hanna Nickel Smelting Co. for the smelting of low-grade lateritic ores, using the Ugine reduction process.

Ferro-nickel smelting in New Caledonia C. G. Thurneyssen, J. Szczeniowski, and F. Michel (*J. Met.*, 1960, **12,** March, 202–205) A description of a new electro-metallurgical Fe–Ni plant installed for the production of a refined alloy from unbeneficiated ore containing 37–50 lb Ni per short t.

The effect of the cooling rate on the solidity of 75% ferrosilicon Yu. P. Vasin (*Izvest. VUZ Chern. Met.*, 1959, (11), 43–45) The ingots of this alloy, which have been cooled at a rate between 60 and 100° per min show a tendency to crumble. A decrease in the cooling rate to 7–10°/min or less or an increase in this rate to 150–200°/min or over maintain the monolithic structure of the ingots and the uniformity of their chemical composition.

The production and properties of new Fe–Al alloys M. Vyklický and A. Kabrhel (*Hutn. Listy*, 1960, **15,** (4), 260–266) Production and properties of Fe–Al and Fe–Al–Mo alloys 'Alfenol' and 'Thermenol' are reviewed. Data given in the literature were checked experimentally, and complemented by others relating to the maximum temp. at which the alloys can be used in practice, and to their corrosion resistance in a number of corrosive solutions.

The problem of the danger of silicosis in ferrosilicon works H. Jung and W. Drees (*Bergakademie*, 1960, **12,** March, 157–159) Methods of measuring dust concentration, radiographic analysis of the dust, and its implications in regard to the danger of silicosis are discussed.

FOUNDRY PRACTICE

Factors influencing the formation of graphite or carbides in cast iron A. Bordes (*Metalen.*, 1960, **15,** May 16, 149–155) These two final instalments of this long article concern the formation of secondary graphite and also of graphite during the conversion of γ- into α-iron. Isothermic conversion is also touched upon together with graphite formation below the conversion temp.—F.R.H.

Factors influencing the formation of graphite or carbides in cast iron A. Bordes (*Metaalinst. TNO*, 1959, Publn., 65, Oct., pp.40) This is a reprint under one cover of the long serial article which appeared in Vol.15 of *Metalen.*

Versatility the 'key' to activities at the Willenhall foundry and engineering works of Arthur Shaw & Company, Limited (*Found. Trade J.*, 1960, **108,** June 9, 715–721) A description of the foundry which is a 'light' foundry is given on the occasion of the 150th anniversary of Arthur Shaw & Company, Limited.—T.G.

Progress from ornament to utility (*Found. Trade J.*, 1960, **108,** June 9, 723–726) Brief descriptions are given of the works of Dartmouth Auto Castings, Limited; Northern Aluminium Company, Limited; and British Piston Ring Company, Limited.—T.G.

Mechanized foundry in North Wales (*Found. Trade J.*, 1960, **108,** May 19, 611–614) The melting and moulding procedures adopted in the new foundry of Austin Hopkinson & Co. at Penygroes, Caernarvonshire, are described and illustrated.—T.G.

Mechanization with flexibility: Details of a new flow-production foundry at the Derby Works of Ley's Malleable Castings Co. Ltd (*Found. Trade. J.*, 1960, **108,** Feb. 25, 221–239) An illustrated description of the new foundry is presented. The foundry was designed on single-shift operation for an output of 250 t per week of a fairly wide range of malleable-iron castings.—T.G.

South Africa's newest steel foundry (*Found. Trade J.*, 1960, **108,** March 10, 291–299) A detailed description of the foundry at the new works of Scaw Metals Limited, Germiston, South Africa, is given. Melting is done in a 10-t Birlec arc furnace and scrap is used for charging. The castings are heat-treated in gas-fired Wellman annealing furnaces.—T.G.

The refractory coating of the cupola. 'Galdacano Stone' A. Alonso-Urquijo Balzola (*Hierro y Acero*, 1960, **13,** Jan.–March, 276–284) The method employed in the use of 'Galdacano Stone', a quartz product of the Biscay region, for lagging furnaces is described and the composition and properties of the stone are given in detail.—S.H.-S.

Selection of blowers for cupolas (**J. d'Inf. Tech. Indus. Fonderie*, 1959, (102), Jan., 1–3) This is a translation of an article which follows a series of papers on the phenomena which accompany the working of centrifugal blowers. Methods of calculating the necessary blowing rate are described.

Fluctuations in the chemical composition of white cast iron on melting in the cupola Z. Hostinský (*Slévárenství*, 1960, **8,** (5), 181–188) White temper iron is made predominantly in cupolas in Czechoslovakia. It is shown that pending the introduction of more up-to-date methods it is possible to reduce fluctuations in chemical composition of the irons, frequent at present, by attention to certain points in the production technology, and by slight changes in the design of the cupolas.—P.F.

Loss of elements by oxidation with cupola melting of cast iron A. V. Kaibichev and V. P. Chernobrovkin (*Izvest. VUZ Chern. Met.*, 1959, (11), 113–118) The smallest loss of the elements (C–0%; Si–10%; Mn–12%) occurs when melting pig iron in the zone of maximum temp. The carbon loss in the viscous liquid iron is governed by the temp. of the droplets detaching themselves from the pigs. The higher the temp. the smaller the loss. Si loss is reduced in the reduction zone but increases in the oxidizing zone. Loss of Mn decreases with a reduction of the height of the melting column in the reduction zone of the cupola but increases in the oxidizing zone, and S behaves similarly.

The effect of metallurgical variables on the mechanical properties of castings made from

13%Cr steel melted in the induction furnace J. Koutský (*Hutn. Listy*, 1960, **25,** (3), 179–188) The effects of variations in the chemical composition and in the production technology on the steel quality were studied. Optimum production methods were ascertained.—P.F.

The use of high quality cast irons to reduce the weight of machines C. Stefanescu (*Met. si Constr. Masini*, 1960, (1), 8–14) The problems raised by the substitution of high quality cast iron to reduce the weight of components are considered. Inoculated cast irons can now be produced with spheroidal or comma-shaped graphite and also ductile irons, all with higher mechanical properties so as to allow of a revaluation of the dimensions of cast machine components.

The organisation and capacity of the foundry industry in the United Kingdom A. R. Parkes (*Koh. Lapok-Öntöde*, 1959, **10,** Oct., 221–231) The paper contains a lecture given by the author on behalf of the Institute of British Foundrymen at the International Foundry Conference in Budapest in 1959.—P.K.

The problem of productivity in the foundry (and elsewhere) G. Halbart (*Fond. Belge*, 1960, **30,** (5), 138–139) The author postulates a theory of 'generalized production', based upon the different fundamental productivities, of work, of capital, and of materials consumed. This in the final analysis, appears nothing more than the profit doctrine of enterprise in a new guise, a concept which he argues, while useful, is neither fundamental nor eternal.

Mechanized foundry for mining equipment Austin Hopkinson & Co. Ltd (*Overseas Eng.*, 1960, **33,** June, 297) A foundry producing 200 t per month of grey iron up to 1 t and steel up to ½ t is described.

Progress from ornament to utility: survey of Midland Works (*Found. Trade J.*, 1960, **108,** June 2, 675–696) This is an account of operations carried out and types of castings handled at works in the Midland area to be visited by the IBF. The works dealt with are Sterling Metals, W. & T. Avery Ltd, Birmingham Aluminium Casting Co. Ltd, John Harper & Co. Ltd, and F. H. Lloyd & Co. Ltd. (June 16, 753–760) A further account of foundries visited during the IBF Malvern Conference: Humber Ltd, Charles Carr Ltd, Shotton Bros, Beans Industries, Duport Foundries, and Bilston Foundries.

Design, construction and operation of a small experimental cupola L. A. de Lacerda Santos and C. Guimarães (*Bol. ABM*, 1960, **16,** Jan., 157–170) Constructional details of an experimental cupola are given: with a hearth diameter of 23 cm it has a capacity of 3 to 4 cwt/h. Details of its operation are given and it suggested that, in addition to some industrial applications, it will be of great value in education, research, and in maintenance shops. Cast iron of controlled compositions at suitable temp. can be obtained (18 refs).—E.S.

The hot blast cupola and its economy F. Varga and F. Wortmann (*Koh. Lapok-Öntöde*, 1959, **10,** Sept., 209–215) After reviewing the advantages of the hot-blast cupola and describing a Hungarian experimental plant in operation, the authors suggest large scale introduction of such furnaces to Hungary on the basis of technical and economic considerations.—P.K.

Melting superheated grey iron in the cupola L. M. Marienbah (*Koh. Lapok-Öntöde*, 1959, **10,** Aug., 177–187) The Russian view and experience on melting superheated grey iron at about 1500°C in cupola furnaces by using hot blast or O_2 are given.—P.K.

Special modification of the cupola process W. Friedel (*Giessereitech.*, 1960, **6,** May, 143–145) Mechanization of the casting process and the modern trend of reducing the wall thickness of castings both require an iron of excellent fluidity and of a temp. higher than usual as holding furnaces are often employed. Of the various means to achieve this aim the addition of CaC_2 was chosen. Optimum results were found with an addition of 2% on the iron and temp. increases of about 45°C with corresponding increase in fluidity were observed, a further increase accompanied the two desired, namely that of the wear of the lining of the cupola.

High frequency coreless induction melting P. S. Sharma (*J. Inst. Eng. (India)*, 1960, **50,** Feb., Part 2, 231–248) Operation, layout, rectification, electrical equipment, protection, and safety are considered in some detail.

Production of high quality cast steels by basic-electric arc melting J. Zotos (*Proc. Industrial Tech. Conf. on Metal Processing*, 1957, 16–17–18 Oct.; *PB* 151308, pp.14) Operating procedure for producing high quality 1045, 4140, high-Ni 4325, 4330, and high-Si 4340 steel castings with an average S content of 0·008% and an average P content of 0·010% is discussed. Improved mechanical properties due to the low S and P content are claimed (20 refs).—A.K.

Desulphurization Diamond Alkali Co. (*Foun. Trade J.*, 1960, **108,** April 14, 462) A rotating drum for increasing metal-slag contact is described.

Desulphurization of cast iron for special purposes C. Bradaschia (*Eng. Min. e Met.*, 1960 **31,** Feb., 57–62) [In Portuguese] (also in *Bol. ABM*).

Desulphurizing of cast iron by an injection process K. Yoneda, M. Okami, and M. Aoki (*Imono*, 1959, **31,** May, 521–527) This paper describes equipment designed by the author to inject CaC_2 or other powders into molten iron, desulphurizing using the injection process and the precautions to be taken. The mechanical properties and chemical compositions of the iron treated with CaC_2, $CaCN_2$, and CaO were tested and the saving of Mg alloy used for producing a ductile iron was studied. The injection process can be used for pretreating ductile iron and improving the mechanical properties of the treated iron.

Consideration as to the relation between the qualities of cast iron and its oxygen content M. Homma (*Imono*, 1959, **31,** May, 477–485) The heredity of cast iron, i.e. the difference in the qualities of cast iron apart from the effects of percentage of C, Si, Mn, P, and S is explained by the oxygen content and minute amounts of metallic elements. The relationship between cast iron structures and the oxygen content and the factors involved for the manufacture of high-tensile cast iron, ductile cast iron, and nodular graphite cast steel are outlined.

A review of high strength cast iron S. Amitani (*Imono*, 1959, **31,** May, 469–476) [In Japanese].

The production of die cast ductile iron bolts for flexible pipe joints R. H. Green (*Bradley's Mag.*, 1960, Summer, 3–6) Casting process, heat treatment, structures, and control are described.

Machinable chill castings J. Sturm (*Koh. Lapok-Öntöde*, 1959, **10,** Dec., 283–297) East German experiments on chill casting of grey iron of 0·70–1·35 degrees of saturation are reported in the paper. The mechanical properties of chill castings are better than those of sand castings. The tensile strength and hardness increase with increasing cooling rate and decreasing degree of saturation. On the basis of the experimental results, the specification for five grades of machinable chill castings is suggested, four of them with minimum tensile strength in the range of 22–34 kg/mm² (14–22 t/in²) and maximum Brinell hardness in the range 220–280.

Cast iron as modified by $CaCN_2$ C. Hisatsune (*Imono*, 1959, **31,** May, 498–509) The mechanical properties of grey cast iron were improved by the addition of $CaCN_2$ to molten metals the nitrogen content of which, especially insoluble nitrogen, was increased to about 100 ppm. The mechanism for modification by $CaCN_2$ was discussed and some processing examples for these types of cast iron were described.

Iron–silicon alloy castings E. Lendvai (*Koh. Lapok-Öntöde*, 1959, **10,** Nov., 245–260) The author reports Hungarian experiments on casting of Fe–Si alloys and draws conclusions concerning the optimum moulding technique, Si and C contents and casting temp., the use of Fe–Ti and nitrogen blowing, and heat treatment.—P.K.

Some studies on the improvement of high-silicon cast iron M. Okamoto, T. Fujii, and K. Majima (*Imono*, 1959, **13,** July, 637–644) This paper describes the results of investigations of the mechanical and corrosion properties of high-silicon cast iron containing small amounts of Ti, B, C, Cu, Ni, or Mg using the electrical resistance, static bending and hardness tests, estimation of the corrosion loss in various acids, and the examination of microstructures.

Experiences in the production of permanent magnet alloy castings G. Bánky (*Koh. Lapok-Öntöde*, 1959, **10,** July, 163–170) After reviewing the development of permanent magnet alloys, the author describes the production of AlNi, AlNiCo, and AlNiCoTi permanent magnet alloy castings in Hungary.—P.K.

Production of quality castings of cast iron M. Loeb (*Bol. ABM*, 1960, **16,** April, 423–434) A discussion in an open meeting at the XIV Congress of ABM, Belo Horizonte, July 1959.

Ferroalloys and inoculants for the production of high-test grey iron H. H. Wilder (*Hierro y Acero*, 1960, **13,** Jan.–March, 246–253) The production of American-type castings of tensile resistance of 30000, 35000 and, 45000 lb/in² is compared with the production of high-test grey iron using alloys giving castings of 30000 and 40000 lb/in². Tables of suitable alloys are presented and precautions laid down for ensuring good practice.—S.H.-S.

Design of high duty iron castings E. G. Donaldson (*Eng. Mat. Design*, 1960, **3,** April, 221–223) A broad survey of principles of casting design to reduce stresses, costs, and for minimum machining.

Practical experience with magnesium inoculated cast iron L. A. Bol'shakov, V. Z. Gavrikov, E. K. Turchenkova, and R. M. Egnus (*Izvest. VUZ Chern. Met.*, 1959, (11), 105–112) The Mg consumption for the inoculation of cast iron under a pressure exceeding the atmospheric, is reduced to one quarter. To obtain a spheroidal graphite cast iron initially containing 0·075–0·093%S, at the inoculation temp. of 1280–1300°, under an air pressure of 2 atm in the ladle-autoclave, an addition of 0·12%Mg suffices. The optimum air pressure in the ladle-autoclave depends on the temp. of the inoculation process and the height of metal over the weighed quantity of Mg.

Specification of nodular cast iron by thicknesses A. Arasti Abaunza (*Hierro y Acero*, 1960, **13,** April, 414–430) After a summary of previous tests by various investigators, the author proceeds to establish a standard type of test, covering properties of unwrought and annealed nodular cast iron, and then describes melts coming from blast and electric furnaces, and compares their advantages and drawbacks. This is followed by a survey of prior inoculations of melts and their repercussions on the physical, mechanical, and chemical properties for different thicknesses of material.

Investigation of some problems regarding cylinder linings of s.g. iron for diesel motors A. Chusi (*Met. si Constr. Masini*, 1960, (1), 32–36) Cylinder linings cast of s.g. irons were fitted to the motors and examined after about 20000 miles service. No wear could be detected and the working surfaces were mirror-like. Some problems connected with the preparation of the metal and the casting are considered.

Graphic resolution of the calculation of risers with the use of exothermic aids C. San José Seigland (*Hierro y Acero*, 1960, **13,** Feb., 152–158) The Caine process with the use of exothermic aids for facilitating solidification of the metal, and the experimental method of Pellini are described and compared.—S.H.-S.

Influence of risers on the cost of metal in a moulded casting D. Escoria Civis (*Hierro y Acero*, 1960, **13,** Feb., 129–134) A mathematical reduction to graphic form for the purpose of rapid calculation of the effect of the cost of risers and sprues on the cost of castings, based on 1000 castings of different types.

Experience in the manufacture of a casting liable to piping E. Jerzina (*Giesserei*, 1960, **47,** June 16, 329) A description of the gating system of a pearlitic casting with a high abrasion resistance, Brinell hardness of 190–220, and high damping capacity.

Investment casting of high-hot-strength 12% chrome steel H. Schneider (*Found. Trade J.*, 1960, **108,** May 5, 562–563) A summary of a paper presented to the Paris Conference of the European Investment Casters Association reporting on the successful investment casting of a 12·5%Cr steel for turbine construction. The composition of the steel, which is highly corrosion-resistant, is adjusted so that it lies on

the border between the phase fields of all-martensitic and martensitic/austenitic steel. The final mechanical properties depend largely on a heat-treatment.—T.G.

Casting and die moulding of spiral castings for hydraulic turbines V. Gomez Oliva (*Hierro y Acero*, 1960, **13,** Feb., 146–151) The process in use by Tallepes F. Gomez of Zaragoza is described and a claim is advanced for reduced cost and improved form of casting as against current practice elsewhere.—S.H.-S.

Composite Shaw-process moulds G. P. Welch (*Found. Trade J.*, 1960, **108,** March 3, 261–263) The moulding technique by the Shaw process for casting two bolsters in steel each weighing about 300 lb is described. Sillimanite was used as the moulding material, it was found that this included some volatile material which produced small surface cavities in the casting. High-temp. firing of the mould will prevent these defects in future.—T.G.

Electrical analogy to the flow of heat from casting to mould J. H. Gittus (*Iron Steel*, 1960, **33,** March, 91–95) The concept of transient heat flow is explained and compared with the flow of current in an analogous electrical circuit. The method of converting the thermal constants to their electrical counterparts is described, and the analogy is applied to the case of a steel slab cooling in a sand mould.

The behaviour of mould materials when rapidly heated in conjunction with the occurrence of scab formation H. G. Levelink (*Metalen*, 1960, **15,** July 15, 220–224) This article follows up one which appeared in vol.11 (1957) of this journal and the author now deals with the influence of sample shape, thickness and type of blacking layer, sand composition and its moisture content, and also the effect resulting from the inclusion of silica flour. An attempt is made to explain the mechanism of the phenomena occurring during rapid heating and to arrive at a correlation between these latter and certain properties of the materials. To conclude, comparison is made between these phenomena and those which occur during the formation of a scab in a mould or on a core. Further articles are to follow.—F.R.H.

The behaviour of moulding materials submitted to shock heating, relative to the appearance of scabs H. G. Levelink (*Hierro y Acero*, 1960, **13,** Jan.–March, 254–267) The uses of sand mixed with dry clay and of sand mixed with oil are compared and the effects of shock heating, giving scabs, blisters, and rope ends, are described and illustrated.—S.H.-S.

Origin and importance of granular structure on castings poured in sand V. Kondic (*Hierro y Acero*, 1960, **13,** Feb., 135–145) The effect of granular structure on the properties of iron and other castings with present methods of control, and recent tests on commercially pure Al and its eutectic are described and discussed with stress upon the need for control of grain size in foundry practice.—S.H.-S.

Observations on internal ruptures in steel castings I. Mnkoff, C. W. Briggs, and H. F. Taylor (*Hierro y Acero*, 1960, **13,** Feb., 124–128) A short review of ruptures in straight bars, rings, and flanged sections of steel, with reference to the distribution of temp. on transverse sections and the effects of insufficient heating.—S.H.-S.

Gases in iron. The danger of Al addition (*Fond. Belge*, 1960, **30,** June, 180) Defects in castings are usually due to the presence of gas dissolved in the metal. A BCIRA study shows that H_2 which has been introduced by reaction with the humidity of the mould is usually the cause of defects under the surface and that the presence of 0·001 to 0·10%Al encourages dissolution.

Thermal stresses in steel castings Z. Nagy (*Koh. Lapok-Öntöde*, 1959, **10,** Dec., 269–274) The author describes the main types of thermal stresses in steel castings, their effects and approximate calculations, and the methods of avoiding and of relieving them.—P.K.

Defects on low-carbon, shell-mould steel castings. I J. Thieme (*Giessereitech.*, 1960, **6,** May, 133–137) Shell moulds were used in a foundry for making stainless-steel castings with good success, but when using the same shell moulds for low-carbon steel, porosity of the surface was observed that led in some cases to a disintegration of the surface. In this part the theory of the causes of this defect is discussed and preliminary studies for finding the actual causes are described.—T.G.

An investigation of hot tearing in steel castings K. Beckius, M. C. Flemings, and H. F. Taylor (*Jernkont. Ann.*, **144,** (2), 109–132) A test casting moulded in a standard flask was used, which measured susceptibility to hot tearing without special instrumentation. Influence of sand strength and composition and pouring temp. was examined; an explanation is given of the relationships between feeding, casting design and external hot tearing and the formation of internal hot tears in steel castings. It is concluded that internal and open tears can be eliminated by adequate feeding.

Ultrasonics improve mechanical properties J. F. Wallace (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308 pp.10) The application of vibrational energy to solidifying metals for refining the 'as-cast' grain size, reducing segregation, and improving the casting detail in certain specific cases is discussed (9 refs).—A.K.

Investigations on pin-holes of steel castings J. Czikel (*Koh. Lapok-Öntöde*, 1959, **10,** July, 157–163) The results of recent melting, casting, and moulding experiments in East Germany suggest that the cause of pin-holes in steel castings may be not only gas porosity as previously believed, but also piping.—P.K.

Modern processes for cleaning and finishing castings S. A. Jannini (*Bol. ABM*, 1960, **16,** Jan., 187–200) The various processes generally in use in foundries are described and compared.

Hygienic problems in foundries J. Bánsági (*Koh. Lapok-Öntöde*, 1959, **10,** Aug., 173–177) The hygienic problems in iron and steel foundries, i.e. the effect of gases, heat, and dust on human physiology are discussed in the paper.

VACUUM METALLURGY

Medium and high vacuum pumping systems for industrial use with special reference to the steel industry H. Noll (*Berg. Hüttenmänn. Monatsh.*, 1960, **105,** June, 140–142) The author describes the various types of vacuum pumps for use on large industrial scales as is required for the vacuum-treatment of steel. The pumps include mechanical pumps such as sliding vane pumps and Root pumps, as well as diffusion and ejector pumps, the latter being also called booster pumps. The combination of various types of pumps for backing purposes of large diffusion or ejector pumps is also referred to.—T.G.

Vacuum melting and casting. Effects on composition—I K. G. Lewis (*Iron Steel*, 1960, **33,** March, 109–112) The behaviour of various constituents during vacuum melting is described, i.e. H, O, N, S, and other elements, including reactive element additions.

Elimination under vacuum of trace elements in ferrous alloys M. Olette (*Rev. Mét. Mem. Sci.*, 1960, **57,** June, 467–480) On the basis of the experiments described an expression is derived for the probability of vacuum elimination of Pb, Mn, Cu, Sn, S, As, P, Al, and Si. Bath O_2 content and type of crucible play an important part in the removal of Al and Si (24 refs).

Gases in casting. Degasification tests in vacuo S. Gallo and G. D'Alessandro (*Hierro y Acero*, 1960, **13,** April, 353–364) The functions and affects of O_2, H_2, and N_2 on the casting of grey and malleable iron, and the slowness of the graphitization process *in vacuo* are described; and the total disappearance of such defects as interdendritic microporosities and blow-holes in all types of castings after submitting them to degasification is claimed.

Sampling on the medium-frequency high-vacuum furnace H. Baumann, H.-H. Domalsky, H. Schenck, and W. Scheibe (*Arch. Eisenh.*, 1960, **31,** March, 133–134) Samples are taken through a furnace fitted with an airlock, which is also used for making furnace additions. Details of the equipment and some results are given.

An experiment on vacuum melting of Cr cast iron M. Kikuchi (*Imono*, 1959, **31,** July, 645–651) (1) Cr content in the cast iron can be greatly increased by vacuum melting without separation of free cementite or ledeburite, in contrast with air melting. (2) In vacuum and air melting, tensile strengths of eight types of cast iron were increased by decreasing the Sc value: for the same Sc value the tensile strength of vacuum-melted cast iron was always 5 kg/mm² higher than air-melted cast iron. (3) In the vacuum melted cast iron the structure consisted of eutectic graphite and ferrite with relatively small C contents while in the steel melted in a vacuum the structure consisted of massive graphite and pearlite without free cementite.

Vacuum degassing of steel. Part 1. Literature survey, and preliminary work D. E. Parsons and W. A. Morgan (*Canada Dept. Mines Techn. Surveys, Res. Rep.* R47, 1959, May 25, pp.75) A survey of the literature on industrial-scale vacuum degassing and casting of steel in USA, Germany, and USSR is followed by an account of work with an experimental 500 lb vacuum stream degassing unit at the Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa (15 refs).

Vacuum degassing of steel J. Verő (*Koh. Lapok*, 1959, **14,** Dec., 569–583) In the first part of the paper, the author discusses thoroughly the mechanism of the removal of H_2, N_2, and CO from molten carbon steels under vacuum and proves theoretically that the limit of vacuum for practical steel degassing is about 1 mm, provided that the hydrostatic pressure is low, as in stream degassing. In the second part, he reviews critically the various melting techniques, methods of stream degassing, and degassing in the ladle under vacuum. The discussion of the paper contains a short description of the experimental stream degassing equipment installed in 1958 in the electric melting shop of the Lenin Steel Works in Diosgzör. On the basis of the experience gained with this equipment, a new and bigger plant will be constructed there shortly.—P.K.

50-inch consumable electrode vacuum furnace to be built at Watervliet Works Allegheny-Ludlum Steel Co. (*Indust. Heat.*, 1960, **27,** March, 550–552) The largest vacuum-melting furnace is to be built by the McGraw-Edison Co. It will produce ingots up to 50 in. dia. and 40000 lb wt., to be used in large forgings and plates for aircraft, rockets, missiles etc.

Materials for high temperature furnaces (*Engineering* 1960, **189,** June 10, 774) A discussion of the properties of W, Mo, Ta, and graphite for high temp. vacuum furnaces internally heated.

Casting of grey iron in vacuo O. Necas and R. Kamensky (*Hierro y Acero*, 1960, **13,** Feb., 111–123) A tabulated report of laboratory tests.—S.H.-S.

Problems of vacuum metallurgy in the production of steel J. Hofmaier (*Berg. Hüttenmänn Monatsh.*,1960, **105,** June, 125–131) This is the introduction to a symposium on the vacuum melting and casting of steel, summarizing the problems involved and discussing the various methods employed including the vacuum treatment of liquid steel.—T.G.

The effect of a reduction in pressure on the reactions taking place in melting and casting of steel E. Schwarz-Bergkampf (*Berg. Hüttenmänn. Monatsh.*, 1960, **105,** June, 133–135) This is a summary of a lecture delivered to a symposium on vacuum melting and casting of steel, dealing mainly with the so-called solubility or saturation product %O, %C in the melt and the formation of CO bubbles within the melt as dependent on its hydrostatic pressure.—T.G.

Model tests as an aid for the study of the degassing process of metal melts T. Kraus and O. Winkler (*Berg. Hüttenmänn. Monatsh.*, 1960, **105,** June, 135–140) Some model tests are described for the study of the factors which determine the rate of the degassing processes and of the whole reaction. The tests reported include those for solving problems of chemical reaction kinetics and the theory of material transport and heat exchange.—T.G.

The degassing of steel by vacuum stream degassing during casting at the Bochumer Verein G. Bandel (*Berg. Hüttenmänn. Monatsh.*, 1960, **105,** June, 142–144) This is an illustrated summary of a lecture delivered to a symposium on

vacuum melting and casting of steel reviewing the new well-known Bochumer-Verein degassing process in which mainly H_2 is removed from the melt.—T.G.

Some observations made on steels that were remelted in a consumable-electrode vacuum arc furnace G. Ogiermann (*Berg. Hüttenmänn. Monatsh.*, 1960, **105,** June, 157–161) The author reports some experience obtained in the remelting of various steels—mostly high-alloy steels—in consumable-electrode vacuum arc furnaces of 25 and 35 kg capacity. If high melting rates are employed it is possible to accumulate at least part of the impurities at the top of the ingot. In remelting a segregation-sensitive high-speed steel it was found that the carbide precipitates were more fine grained. In all cases the gas content of the steels was reduced substantially.—T.G.

Experiences gained in the vacuum treatment of open-hearth steels H. J. Därmann (*Berg. Hüttenmänn. Monatsh.*, 1960, **105,** June, 144–151) The Dortmünd–Härder–Hüttenunion process is described and the results obtained are discussed. The heat losses incurred in the vacuum treatment have been overcome by adding electric resistance heating and the trouble with the lining has also been eliminated. The H_2, O_2, and oxide contents of vacuum-treated steel are always lower than those of the untreated steel, but the main feature is that treated steel shows much more uniform contents of H_2, O_2, and oxides. Alloying elements may be added in the vacuum tank, deoxidizing agents may be added at the same time. The advantages brought about by vacuum treatment as regards working properties and the mechanical properties of the finished part are also mentioned. In the discussion, a number of new vacuum-treatment plants working on this principle are described.

The principles underlying the vacuum degassing of steel by the circulation degassing process H. Maas (*Berg. Hüttenmänn. Monatsh.*, 1960, **105,** June, 151–155) The principles of the vacuum degassing of steel by the Ruhrstahl-Heraeus circulation degassing process are discussed and the degassing process is described. The progress of degassing with time is explained, owing to the low hydrostatic pressure the elimination of CO is very thorough, the same applies to the H_2; both gases assist one another in their removal. The circulation velocity and the mixing of treated with untreated melt has been studied with radioactive gold. It was found that for a 100-t ladle, complete homogeneity of gold radiation was obtained after 4 min, i.e. in this time the total content of the ladle has taken part in the degassing process.—T.G.

Ladle-to-ladle degassing of steel E. Dyble and G. E. Danner (*Found. Trade J.*, 1960, **108,** Feb. 18, 196) The ingot mould is placed in a vacuum tank, on top of which a pony ladle is positioned into which the metal is poured from the furnace ladle; degassing takes place during teeming from the pony ladle. It is mainly H_2 that is removed with consequent soundness of the castings. The pouring time is controlled by the size of the pony ladle nozzle. The applications of vacuum-degassed steel castings are enumerated.—T.G.

REHEATING FURNACES AND SOAKING PITS

New soaking pits at Newcastle W. A. Hannaford (*BHP Rev.*, 1960, **37,** Feb., 26–27) An illustrated account.

'U-fired' soaking pits K. E. Dinius (*Iron Steel Eng.*, 1960, **37,** April, 158–162) A general account is given of the soaking pit installations serving the new 53-in blooming mill at the South Works of United States Steel Corp., in which the flues are on the same side of the pit hole proper, and firing is in a horizontal 'U'. This permits a ratio of pit area to building area of about double that of standard regenerative design, and about equal to that of modern recuperative design, and individual pit draught control is provided.

An arrangement for bottom heating in the malleablizing zone of the continuous furnace V. A. Shirinkin (*Stal'*, 1960, (6), 567–568) An improved continuous preheating furnace for a rolling mill is briefly described. Bottom heating removes dark patches which are otherwise slow to disappear.

Increasing the output of blooming mill soaking pits N. A. Volobuev, M. M. Kotrovskii, A. P. Shlyakhov, A. A. Kogadeev, M. S. Shklyar, and E. I. Kazantsev (*Stal'*, 1960, (5), 473–475) The reconstruction of pits to take eight ingots instead of six with reduction of specific fuel consumption by 10–12% is described.

A study of the influence of the heating of steel ingots in soaking pits R. F. Costa, E. Grees, N. B. Pires, D. de Almeida, J. A. P. Madeira, D. Gabriel, R. C. Fernandes, and N. Borges (*Bol. ABM*, 1960, **16,** Jan., 39–69) This investigation arose from the need to establish a programme for the soaking pits at CSN; these pits consist of pairs of gas-fired reverberatory furnaces of 45 t capacity and recuperator furnaces of 100 t capacity. The 40 in. two-high reversing mill was used to measure ingot plasticity since this gave a measure of the uniformity of ingot temp. Details of the calculations and results of the trials are given. It is concluded that: (i) values for the plasticity are more accurate for the first passes; (ii) synchronized recording meters were found to give sufficiently precise measurements of the electrical energy absorbed in the pass; (iii) the plasticity varies with ingot height, speed, and pass reduction but these effects are not large; (iv) mill maintenance time is reduced.—P.S.

Future trends in preheating and thermal treatment furnaces L. G. Aksel'rud, M. A. Glinkov, V. N. Grigor'ev, A. E. Lifshits, and R. M. Mantsev (*Stal'*, 1960, (6), 562–567) Soaking pits, kilns, and heat-treating furnaces are reviewed with special reference to the needs of automation.

Electric-resistance reheating of steel bars for working W. Stich (*Elektrowärme*, 1960, **18,** June, 196–204) The direct resistance reheating of steel bars for forging is described. The square ends of the bars are brought into contact with water-cooled copper contacts, the steel bars are heated by low-tension currents. The electrical details are given including the necessary instrumentation. The advantages of direct electric heating on surface quality, microstructure, etc., of steel for working are pointed out. The economics of the process are also dealt with.—T.G.

Induction heating in drop forging A. Terény (*Koh. Lapok*, 1959, **14,** Nov., 516–522) The paper deals with the use and economy of induction heating in drop forging. The usual 3–4% scaling loss in gas furnaces can be reduced to ½% by using induction heating; this, in turn, doubles or trebles the life of the die. Sometimes, for special reasons, protective atmosphere is also used.—P.K.

Medium-frequency induction heating before hot working as a means for the increase in productivity in forges F. Scheffler (*Elektrowärme*, 1960, **18,** May, 160–165) The author describes the development of induction heaters for the material to be worked by hammers, presses, forging machines, and screw and bolt presses.—T.G.

Modern soaking pits for blooming mills S. D. Gekhtman (*Metallurg.*, 1960, (1), 34–37) A description of a modern design for heating soaking pits from a central burner in the bottom and of a design for heating with two top burners are given.

Automating the preheating furnaces for the continuous thin sheet mill M. D. Klimovitskii and A. E. Pratusevich (*Metallurg.*, 1960, (2), 29–31) Since the main factor for improving the quality of the heating before rolling is automation, a basic system of zonal control of the heat processes in the continuous furnaces for a mill with five roll stands is described.

Heating blanks for stamping in salt baths N. F. Vyaznikov, V. G. Khoroshailov, and A. N. Popandopulo (*Vestn. Mashin.*, 1960, (2), 71–72) $BaCl_2$ was used as a medium for heating the metal to 1250°. The undermentioned comparison figures for heating in a chamber and in the salt bath are characteristic: Steel type 2Kh13, blanks 60 mm dia., require 25–30 min to heat up to 1250° in the chamber and only 7–8 min in the salt bath. Metal loss by oxidation in the chamber amounts to 1·10% of the weight of the metal and in the salt bath only to 0·24%.

Prevention of transverse cracks when heating ball-bearing steel V. D. Avdeeva, A. N. Dyskin, and G. Ya. Kozina (*Metallurg.*, 1960, (1), 39) At the Serov Combine, ball-bearing steel ingots rolled on the large 850 mill, cooled after casting and then heated in the pits, showed a proportion of rejects for transverse cracks of 6·5%. In some cases even up to 25%. The pit temp. on loading was 300–400°. The works laboratory have found that a preliminary tempering at 680° and loading into pits in a compartment at 200° reduces the rejects for this cause to 0·1–0·2%.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Some recent heat-treatment developments J. McMullen (*Iron Steel*, 1960, **33,** March, 101–104) Several types of Efco furnaces are described and illustrated, including a multi-purpose horizontal closed quench furnace, an electrically-heated multi-purpose furnace with endothermic generator, electrically-heated pit carburizing furnaces, a vertical cylindrical multi-purpose furnace, and annealing and hardening furnaces.

Development of modern heat-treatment processes and confirmation of their advantages in practice W. Connert (*Stahl Eisen*, 1960, **80,** Aug. 4, 1049–1060) The theory of heat-treatment of steels is discussed and plant is described for the continuous simultaneous annealing of various types of steels. The main feature of this process is combination of a high (830–860°C) and a low (760–800°C) annealing temp. With intermediate cooling to 650–700°C and a final controlled water-quenching from 720–680°C. The advantages brought about by this process are noted. The step-wise induction hardening of cold-rolling rolls is also described. The report is followed by a lengthy and very interesting discussion.—T.G.

New use for radioactive tracers—checking furnace atmospheres C. O. Reiser and K. L. Wilson (*J. Met.*, 1960, **12,** March, 234–235) The use of ^{85}Kr for examining the atmospheres of heat-treatment furnaces is described. The technique is used for determining the gas flow and the concentration of the original atmosphere remaining at any time during purging.

New hardening process for rail heads D. M. Rabinovich, O. L. Gurfinkel', and V. S. Serebryakov (*Stal'*, 1960, (7), 650) A process for h.f. induction heating followed by a water spray is described.

Flame hardening machines and equipment P. J. Kool and J. van der Linde (*Metalen*, 1960, **15,** July 15, 228–233) This article consists of numerous illustrations with brief descriptions of various types of heavy and light machines and equipment available for the surface hardening of workpieces, castings, crankshafts, gears, railway wheel rims, etc.—F.R.H

Temperature uniformity in heat-treating H. N. Ipsen (*Met. Treatment*, 1960, **27,** Feb., 63–66) The author emphasizes the importance of temp. uniformity on case and core properties and shows that rapid uniform heating can be effectively carried out by convection employing baffles in the furnace design.

Large gantry furnace at Douglas has new features for heat-treating superalloy missile components [Douglas Aircraft Co.] (*Indust. Heat.*, 1960, **27,** Feb., 258–263) This new, large installation for heat-treating Thor components covers 45×125 ft, and has a gantry-quench and a pit-type draw (tempering) furnace, and an oil and a water quench tank. The gantry furnace has a 74 in i.d. vestibule and 18 ft high heating compartment; its four 100-kW zones give close-tolerance temp. up to 2000°F. The pit-type furnace has a 74 in i.d. work area, 216 in deep, and uses 200 kW to maintain temp. up to 1250°F.—K.E.J.

Study of heat-treatments for low coercive force 14 to 17% aluminium-iron alloys D. Pavlovic and K. Foster (*J. App. Phys.*, 1960, **31,** Supplement, May, 231s–232s) A study was made of the effects of atmosphere, temp. of initial annealing and composition on the coercive force of 14 to 17%Al–Fe alloys. A combined effect of heat-treatment atmosphere and temp. of initial annealing is shown to exist in this alloy region and is discussed in terms of a possible influence of purification and atomic

ordering. Observations made on the binary Al–Fe iron alloys show that the heat-treatment controls both the grain size and the distribution of the second phase in ternary alloys which in turn affect the magnetic properties.

Heat flow in walls of industrial furnaces K. O. Borchers (*Arch. Eisenhütt.*, 1960, **31,** June, 343–350) A method is developed by means of which the heat storage in walls of finite thickness can be determined with a few simple calculations for any given heating process, which lies between a sudden change of temp. of the wall interior and a uniform rise of the interior wall temp. Diagrams are constructed from which the degree of saturation can be derived for heating processes which start from (*a*) a rectilinear, and (*b*) a curved initial temp. distribution (17 refs).

Theory of the pressure pattern in extended industrial furnaces M. Hansen (*Arch. Eisenhütt.*, 1960, **31,** June, 337–342) The importance of static pressure in obtaining satisfactory operation is discussed, and the various factors influencing pressure changes are reviewed and treated theoretically. The results are illustrated by examples from practice.

Heat-treating the stainless steels. V S. W. Cole (*Indust. Heat.*, 1960, **27,** Feb., 297–310) Detailed data are given for stress-relieving, tempering, and annealing treatments for martensitic steel type 403, 410, 414, 416, 420, 420F, 431, 440A, 440B, 440C, and 440F.—K.E.J.

The heat-treatment of spring alloys for working at elevated temperatures A. G. Rakhshtadt, V. A. Sol'ts, and V. F. Moiseev (*Stal'*, 1960, (5), 468–472) E1702 steel can be used up to 300°C by adding 5%Mo, and Ni alloys working up to 500° are also noted. Tests of various steels and other alloys with different heat-treatments are described.

Heat-treating T58 and J85 engine components in elevator type furnace [General Electric Co.] (*Indust. Heat.*, 1960, **27,** March, 530–532) The gas-fired furnace, giving temp. up to 2150°F, is rated at $1{\cdot}5 \times 10^6$ Btu and is used for heat-treating in H_2 brazing and bright annealing.—K.E.J.

Studies on the heat-treatment of silicon steel sheets. II T. Takei, H. Mizuno, and K. Haga (*Rep. Sci. Res. Inst.*, 1956, **32,** July, 101–106).

Unusual jobs create interesting heat-treating solutions at Los Angeles Plant of Lindberg Steel Treating Co. (*Indust. Heat.*, 1960, **27,** March, 657–668) Details are given of a versatile heat-treating installation which can handle non-routine work, e.g. the third-stage rocket shell for the Vanguard satellite. Hard ductile cases are produced on low-carbon steels by Chapmanizing, and wear- and corrosion-resistant surfaces on stainless steels by Malcomizing (details given).—K.E.J.

Installation and operation of gas atmosphere generators E. C. Bayer (*Indust. Heat.*, 1960, **27,** March, 517–532) Data are given for the operation of exothermic and endothermic controlled-atm. generators operating on natural gas and air. They include the compositions of atm. obtainable, generator design, applications, control, safety, and maintenance.

Selas hydrogen generator plant features new system of generation and purification (*Indust. Heat.*, 1960, **27,** Feb., 336–338) Details are given of a fully automatic plant producing 1000–10000 ft^3/h of H_2 of up to 99·98% purity. The main process is conversion of hydrocarbon feedstock to H_2 in a steam-methane reforming furnace with radiant burners; various means of removing impurities (except inert gases) are incorporated.—K.E.J.

Special study of waste heat recovery from industrial furnaces G. N. Critchley (*J. Inst. Fuel*, 1960, **33,** July, 353–356) The programme for a forthcoming conference (in 1961).

Study on continuous gas carburizing. VI. Some effects of carburizing abilities on the properties of carburized steels A. Tsutsui, T. Furumoto, and M. Ichihara (*Nippon Kinzoku*, 1959, **23,** April, 206–208) Experimental results show the effects of differences in carburizability on physical, mechanical, and other properties. The effects on quench distortion, residual stress, and bending behaviour are also discussed.—K.E.J.

Flame-hardening of piston-ring grooves of marine engines K. Falkenmayer (*Schweissen Schneiden*, 1960, **12,** May, 241–243) A machine is described and illustrated for the flame-hardening of the piston-ring grooves of large Diesel engines for marine application. The pistons are of cast steel with 0·35%C. The depth of hardening varies between 2 and 3 mm.—T.G.

Rapid heating techniques A. M. Ayvazian (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308, pp.9) Investigations of rapid heating technique on thick-walled hollow cylinders using high-frequency and gas heating. The complete hardening and tempering cycle took approximately 2 h compared with 15½ h for the conventional cycle. In three out of four cases the mechanical properties were adequate, though grain size variation across the section was rather inconstant.—R.D.

The nitriding of ferro-chromium and ferro-manganese B. Vécsey and L. Wisnyovszky (*Koh. Lapok*, 1959, **14,** Sept., 407–409) The authors describe experiments on alloying solid and liquid Fe–Cr and Fe–Mn with N_2 by using NH_3.—P.K.

Nitriding of iron chromium manganese alloy (*Nat. Met. Lab. Ann. Rep.*, 1958–9, 24) Vessels for nitriding up to 120 lb of the alloy were designed.

Insertion treatment of nitrogen into ferrite J. Pomey, M. Mouflard, A. Royez, and M. Wintenberger (*Compt. Rend.*, 1960, **250,** March 7, 1845–1846) Slightly below the eutectoid temp. of the Fe–N diagram, it is possible to fix and diffuse N_2 in ferrite and maintain this state by heat treatment. This surface treatment raises the fatigue limit by 85%; the resulting structural modifications are discussed.

Continuous cycle heating cooling furnace provides a better structure control in annealing for machining A. G. Sturrock (*Blast Furn. Steel Plant*, 1960, **48,** June, 581–583, 590) The importance of uniformity and reproducibility of structure in obtaining machineability are emphasized, and the operation of a continuous roller hearth, cycle heating, and cooling furnace installed by the Wyckoff Steel Co. at its Chicago plant is described.

Tests of heat treatment for cast components of T36 and M17 steels C. Wanyorek (*Met. si Constr. Masini*, 1960, (1), 65–69) Some general recommendations are made, for example, annealing at 860–900° for 2–3 h and cooling in the furnace and quenching in oil from 840–860° followed by a single tempering at 650° for 2 h and then cooling in water.

The essentials of the thermal hardening of tubes by a water jet N. Yu. Taits and A. S. Kadinova (*Stal'*, 1960, (7), 655–657) Jet cooling methods give more uniform properties than bath quenching. The characteristic cooling curves for pipes treated in this way are obtained and the heat extraction coefficient depending on metal temp., water pressure, and wall thickness is calculated.

Electro-tempering of 9KhS steel V. T. Cherepin (*Izvest. VUZ Chern. Met.*, 1959, (11), 97–104) An investigation of the transformation in this steel with electrical heating show that the first transformation during tempering, with a rate of heating of 1000–8000°/sec occurs between 200–320° and the third between 530–670°. Austenite forms at 800–850°. A relation has been found between the third transformation process and the decay of residual austenite in quenched steel. The results obtained have contributed to working out practical conditions for the electrical tempering of components made of this steel.

Heat-treatment at Babcock & Wilcox Ltd (*Met. Treatment*, 1960, **27,** March, 113–118) The article describes in some detail the plant for heat-treating drums, pipes, tubes, and manifolds. Each furnace is described with its instrumentation, performance, and design figures.—A.H.M.

Jet cooling system of continuous annealing furnace speeds production of tinplate strip (*Indust. Heat.*, 1960, **27,** Feb., 318–324) Strip is processed at 500–1200 ft/min in reduced space, using eight passes only. The fast cooling section has 54 jet cooling units, which circulate protective-atmosphere gas (cooled in a heat exchanger), reducing the strip temp. from 900 to 250°F.—K.E.J.

The annealing of buttwelded saw segments N. Hajto (*Koh. Lapok*, 1959, **14,** July, 297–302) A suitable annealing process has been devised experimentally in order to avoid the cracking of buttwelded high-speed steel saw segments.

Effect of preheating in the range of recovery on the results of recrystallization annealing of deep-drawing sheet G. Odone and V. Berruti (*Stahl Eisen.*, 1960, **80,** July 21, 1018–1023) Deep-drawing sheet with about 0·07%C was used for the tests. Preheating to temp. between 400 and 500°C brought about an overall reduction in annealing time of about 20%, a reduction in hardness and a more uniform microstructure. The working properties of the sheet were however not markedly affected by the two-step annealing process. It is thought that the elimination of lattice defects in the mosaic blocks during crystal recovery is a major requirement for an undisturbed crystal growth during recrystallization.—T.G.

Promotion of cubic grain growth in 3% silicon iron by control of annealing atmosphere composition D. Kohler (*J. App. Phys.*, 1960, **31,** Supplement, May, 4088–4098) It has been found that by controlling the concentration of impurities in the annealing atmosphere the growth of grains having the (100) plane parallel to the sheet surface can be greatly improved. From this orientation dependency of the surface energy there results a discrepancy between theory and observed fact of (100) surface energy growth. It is proposed that adsorption by the metal surface of atmosphere constituents in a very special manner can accomplish a change in relative surface energy so that the (100) plane becomes the lowest energy crystal plane.

Controlled atmosphere cycle annealing of transformer laminations in electric roller hearth furnace Webcor Inc. (*Indust. Heat.*, 1960, **27,** Feb., 272–276) An electrically heated roller-hearth furnace, 120 ft long, anneals 4500 lb of silicon steel laminations per h. The laminations are handled from punch presses through to the loading area by conveyor. The furnace has a preheat section, three annealing sections, an insulated cooling section, a three-zone water cooling section with forced convection, and an air blast section.—K.E.J.

Cold-rolled dynamo steel annealed in continuous furnaces N. F. Dubrov, L. V. Mironov, and M. I. Kolov (*Stal'*, 1960, (6), 543–547) Electrical properties are related to grain size and depth of decarburized layer and the use of a critical degree of deformation have the greatest effect on the properties. Continuous annealing in H_2 is recommended.

Effect of isothermal magnetic annealing on the magnetic properties of Fe Co alloys at room temperature H. Masumoto, M. Takahashi, and M. Sugihara (*Nippon Kinzoku*, 1959, **23,** April, 229–232) Magnetic annealing only affected the magnetization and magnetostriction in the temp. range between the γ α transformation temp. and ~400°C. Max. permeability and saturation magnetostriction changed remarkably when the alloys were annealed at ~900°C and the temp. of superlattice transformation, especially with low-Co alloys. The 76%Co–Fe alloy gave anomalous results. The effect is explained in terms of superlattices and a lattice abnormality caused by magnetostriction.—K.E.J.

The hardening of steels. Cooling velocity and TTT curves (*Tecn. Indust.*, 1960, **38,** March, 352–354) The factors determining the choice of quenching technique are discussed.—P.S.

Graphitization of nodular graphite cast iron during tempering P. Rys (*Inst. Hierro Acero*, 1960, **8,** Jan., Special Number, 16–29) A review of the processes that take place on tempering quenched nodular cast irons in the range 22–710°C is given with particular emphasis on secondary graphitization. Dilatometric investigations, supported by metallographic, mechanical, and other physical tests have been carried out on samples from one cast of composition (3·13%C, 3·12%Si, 0·56%Mn, 0·073%P, 0·010%S, 0·04%Cr, 0·08%V, and 0·078%Mg). With normal periods of time at low tempering temp. behaviour is the same as

in Si steels. At high temp. secondary graphitization occurs very rapidly, its development being affected by the formation of graphite nuclei which depends on the state of the matrix. This state also affects the rate of growth of the graphite and can be modified by different treatments. The mechanism of nucleation and growth is discussed and it is shown that structural defects have a decisive influence on both (32 refs).—P.S.

FORGING, STAMPING, DRAWING, AND PRESSING

Forge development. New 800-ton press at Firth-Brown (*Iron Steel*, 1960, **33**, March, 96) The design and operation of the press installed at the reconstructed forge department are described.

Views of the development of the Hungarian forging industry L. Logodi (*Koh. Lapok*, 1959, **14**, June, 275–278) The importance of adequate heating facilities, introduction of manipulators, extension of drop-forging and improvement of descaling in the Hungarian forging industry is discussed with regard to the changes in the processing industry.—P.K.

Design principles of forging R. C. Jones (*Eng. Mats. Design*, 1960, **3**, March, 165–168) Some practical aspects relating to design of forging dies are given. Examples of die design and forging procedures for several components are described.—A.T.

Experiments with a forging machine. II. Some experiments on an air-hammer using an accelerometer T. Awano and T. Yamakawa (*Rep. Gov. Ind. Res. Inst. Nagoya*, 1955, **4**, May, 198–205) [In Japanese].

Shock isolating foundation for a drop-forging hammer N. Fukuo and T. Kozuka (*Rep. Gov. Ind. Res. Inst. Nagoya*, 1955, **4**, June, 239–246) [In Japanese].

Giant dies for hot forging E. G. Donaldson (*Met. Treatment*, 1960, **27**, March, 88–90) A 4500 t hydraulic press used for fabricating reactor vessel plates up to 4 in. thick at 900°C is described, together with its operation and plant layout. Dies are made of an unalloyed ferrous-cast material giving satisfactory service after pressing some 600 plates.—A.H.M.

Cold forging (swaging) process S. Valencia (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308, pp.7) Description of the cold forging process and the characteristics of the machine. Applications, and advantages over conventional type swaging machines are discussed.—R.D.

Manufacturing improvements in the fabrication of 155 mm shell (metal parts) J. J. Obren (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308, pp.8) Manufacturing improvements in the hot forging of 155 mm shells are reported.—A.K.

Progress report on the development of a practical forgeability test H. M. Green (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308, pp.13) Criticism of the existing methods of forgeability testing is given and the development of a more simulative test is described.—R.D.

Fabrication of clad steels S. Rowden (*Eng. Mat. Des.*, 1960, **3**, June, 334–338) Forging, forming, and welding of steels clad with ferritic or austenitic steels, Ni or monel are summarized.

Heavy engineering fabrication at G.E.C. T. J. Palmer (*Weld. Met. Fabr.*, 1960, **28**, May, 174–184) An illustrated account of operations at Fraser and Chalmers Eng. Works, Erith. Equipment is reviewed and testing methods are considered.

Ring rolling plants designed for automatic operation (*Iron Steel Eng.*, 1960, **37**, April, 178, 180, 183) The fully automatic forging press and ring rolling mill marketed by Wagner and Co. of Dortmund are described.

Study of the behaviour of various steels during dynamic hot upsetting S. Henkel (*Freiberg. Forschungsh.*, 1956, (**B10**) pp.77) The effect of shape of the sample, degree of working, temp. composition and microstructure of the steel, rate of deformation and surface quality of the sample and tool on the behaviour of a number of steels during upsetting was studied. The experiments are described in detail and the results obtained reported in full. It was found *inter alia*, that at high temp. the resistance to deformation remains constant or almost constant. A relation is derived from the experimental results relating the mean resistance to deformation to temp. of working rate of deformation, and composition of the steel (45 refs).

Some examples of small forgings in long series and the problems that may arise E. Ehrenstein Pollack (*Hierro y Acero*, 1960, **13**, Jan.–March, 285–288) The manufacture of small forgings in F111–F114 steel for use in railway rolling stock, runnin gmachinery, autocompressors, friction presses, and drop hammers is briefly described, with hints as to avoidance of unnecessary difficulties.—S.H.-S.

The working capacity of spheroidal graphite cast iron Chang Tso-mei, Shu U-yung, Gau Tze-ming, and Kuoh Sheng-chuen (*Freiberger Forschungsh.*, 1957, (B16), 82–107, with an appendix on **'The behaviour of spheroidal graphite cast iron during forming and shaping'** Bending, tensile, and compression tests on spheroidal graphite cast iron showed that the best temp. range for hot-working is 700–1100°C, but even within this range the maximum permissible degree of working depends on the stress conditions, i.e. higher degrees are allowed in compression than in tension. The degree of deformation depends also on the rate of deformation and is higher for lower rates. The study reported in the appendix showed that spheroidal graphite cast iron becomes brittle between 200 and 650°C, but this changes with the rate of deformation. The iron can be rolled and drop-forged.—T.G.

The resistance to deformation of steel C 45 during hot working at medium deformation rates W. Lueg and U. Krause (*Stahl Eisen*, 1960, **80**, Aug. 4, 1061–1067) Experiments on the resistance to deformation during upsetting of steel C 45 at 700–1100°C at deformation rates between 5 and 20 s^{-1}, i.e. corresponding to the working rates of hammers and presses, showed that the deformation rate of steel is best expressed by an exponential function. Agreement between experimental results and theory was good. The experiments are described fully.—T.G.

Mechanization of some labour-consuming operations in the forging shop Yu. T. Khudik and V. A. Lankin (*Metallurg.*, 1960, (4), 36–38) The specially constructed manipulators of the 5- and 3-t forge hammers at the 'Dneprospetsstal' ' are described. They can now fit into an electrical control scheme so that this operation is automated.

Fabricating steel for Atlas missiles General Dynamics Corp. (*Weld. Met. Fabr.*, 1959, **27**, Oct., 370–372) An illustrated account of a large radial stretch press and a spot-welding machine with a description of the welded tanks produced.

Developments in metal cutting and shaping (*Weld. Met. Fabr.*, 1959, **27**, Nov., 412–417) An illustrated account of equipment for shrinking, stretching, mechanical cutting, and bevelling, and forming presses.

A press for bending steel sheets of up to 250 mm thickness, the most powerful in Europe (*Usine Nouv.*, 1960, March, 39) A press of 7200 tons pressure for bending steel sheets of up to 250 mm in thickness and 12·2 metres in length at the plant of Phoenix Rheinrohr AG, in Mülheim is described as to its general characteristics and method of operation.

Solid wheels, without tyres, for railways, trams, and tubes Société des Aciéries et Forges de Firminy (*Tecn. Indust.*, 1960, **38**, March, 349–351) A description of the equipment at Les Dunes in France, which produces wheels from solid billets by a sequence of press forging and rolling is described.—P.S.

Working metals by detonating explosives J. H. Cook (*Sheet Metal Ind.*, 1960, **37**, April, 253–258) The author deals with the principles of applying explosives to metal forming, giving examples of processes which have been successfully performed by means of detonating explosives. These processes include jointing of pipes, compacting of metal powders, engraving on metals, cutting, and boring. The paper is followed by a discussion.—A.H.M.

Investigation into the wear of punches and dies W. Crasemann (*Sheet Metal Ind.*, 1960, **37**, April, 259–262, 266) The author describes the results of several years work at the University of Hanover, starting with a brief outline of the mechanics of shearing of sheet metal. He then differentiates between face and surface wear of the tool. Face wear produces flash, both increasing similarly with number of cuts. It is proposed therefore to use flash as an index of tool wear. The paper is followed by a discussion.—A.H.M.

Coil processing line (*Sheet Metal Ind.*, 1959, **36**, Dec., 805, 806) A brief description is given of the recently installed coil processing line of the Standard Pressed Steel Co., Pennsylvania, which handles steel coils 48 in wide. The line includes a 'Flying Press' used for forming, shearing, blanking, and piereing operations. These are carried out while the dies and strip are in continuous motion.—A.H.M.

Relations in the calculation of drawing-die sets for wire-drawing machines L. Nusser (*Stahl Eisen*, 1960, **80**, July 7, 950–952) The calculation of wire-drawing die sets is still best done with a slide-rule. The author reviews recent publications for this calculation and quotes some formulae for which he gives examples for solving on the slide-rule.—T.G.

Chemical changes of soap-base lubricants during wire drawing P. Funke jun., B. Werdelmann and W. Lueg (*Stahl Eisen*, 1960, **80**, July 7, 918–925) Gas-chromatographic analysis showed that the residues of the soap-base lubricants found on the wire after drawing have undergone a change in their chemical structure with respect to the fatty acid. After drawing, fatty acids were detected that were not present in the original lubricant. Variations of the wire-drawing process do not have an effect on these chemical changes.—T.G.

Steel wire of martensitic structure K. Schlegel (*Stahl Eisen*, 1960, **80** July 8, 952–953) The author summarizes and comments on a paper by T. Nishioka (*Tetsu to Hagane*, 1958, **44**, 151) on the production of heat-treated steel wire of low carbon content and high tensile strength which is there called 'martensite wire'. The heat-treatment is carried out in a special furnace in which the wire is directly heated by an electric current to 950°C in a protective atmosphere, quenched and tempered in a lead bath. The special feature of the direct heating is that the wire is still heated by the current during the quenching operation, that is that the quenching rate must be substantially lowered.—T.G.

Hot extrusion of gun tubes J. H. Penrose (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308, pp.10) The hot extrusion of 24, 90 mm, T119 tubes from 12 ingots and 12 forgings in a 12000 t horizontal press is described. The mechanical properties of the tubes extended from ingots was satisfactory but due to low R.A.T. values only three extrusions produced from the forged billets met specification requirements.

New extruding techniques developed for high-temperature steel and pure beryllium L. M. Christensen (*SAEJ*, 1960, Feb., 35–39) Details are given for the extrusion of thin steel sections, for example a T-section 1·5 × 1·5 in with 0·062 in thick legs. The steels extruded are SAE H 11 (5%Cr hot work die steel) and A–286, a heat resisting steel. The equipment developed for producing these sections is described, together with a summary of results and proposed future research.—A.H.M.

Cold impact extrusion of steel H. Eberspächer (**Werkstatt Betrieb.*, 1958, **91**, Oct., 605–608) A general review is given of the present position in the cold extrusion of steel; technical and economic factors are discussed (20 refs).

Process engineering from prototype to production of the 8-inch M 106 H.E. shell by the hot cup-machine-cold extrude method H. J. Babcock (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308, pp.28) Outline of the process for the production of the 8-in. M 106 H.E. shell and discussion of the reasons for the selection of this process. Quantity of steel used per shell is cut by 30% in conventional pierce and draw process with a price reduction of 25%.—R.D.

Rotary extrusion of liners C. Zglenicki (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308, p.1, title only) The report is classified as confidential and is excluded from the publication.—R.D.

ROLLING MILL PRACTICE

Durgapur makes steel—Rolling mill section (*Brit. Steel.*, 1960, **26,** May, 163–165, 167–169, 171–172) The rolling mill plant, wheel and axle plant, engineering workshops and foundry, for all of which Davy and United Engineering Co. Ltd are responsible, are described.

Improving the specific yield of steel rolling mills I. Frantiu (*Met. si Constr. Masini*, 1960 (2), 134–139) An analysis of metal losses due to scaling, cleaning, cropping, etc., and measures to reduce them.

The geometry of the instantaneous deformation focus during the hot-rolling of tubes on the Pilger mill A. P. Chekmarev and A. A. Chernyavskii (*Izvest. VUZ Chern. Met.*, 1959, (11), 47–62) A graphical analytical method is explained making possible a relatively simple determination of the geometrical elements of the instantaneous deformation focus (angle of bite, length of the deformation focus, and initial and final height) for the hot-rolling of tubes on the Pilger mill under consideration of the actual grooving of the roll, of its rotation during deformation and of the period during which deformation is imparted.

Deforming forces in roughing pass sets G. Zouhar (*Bergakademie*, 1960, **12,** Jan., 36–37) Rolling forces were measured on an experimental mill at the Metallformungsinstitutes der Bergakademie Freiberg, rolling the series round-oval, square-oval, square-diamond, and diamond-diamond.

Calculation of the electric power for hot-rolling alloy steels V. A. Shubenko, Ya. N. Shpunberg, V. N. Ustelemov, and V. D. Mel'chekov (*Izvest. VUZ Chern. Met.*, 1959, (11), 73–82) Conversion coefficients have been calculated by means of which it is possible easily to determine the power consumption, the moments, and the pressures of the metal on the rolls for certain alloy steels which are the subject of these investigations. This method may be applied also to the calculation of conversion coefficients for other types of steel.

The measurement of rolling power and torque in the rolling mill, and their recording L. Eberlein (*Bergakademie*, 1960, **12,** March, 144–149) Instruments and equipment used for measuring, transmitting, and recording these quantities are described and illustrated.

On the hydrodynamic theory of hot rolling A. Kneschke (*Freiberg Forschungsh.*, 1957, (**B16**), 5–34) The author develops a theory of the rolling process based on rheological considerations and places particular emphasis on the dependence of the mechanical quantities on the rolling parameters. The effect of the rolling parameters on the rolling force, resistance to deformation and the rolling momentum is presented in full and compared with measured values. Agreement is fair (21 refs).—T.G.

Calculation of the mean resistance to deformation and of the rolling force in hot and cold rolling A. S. Geleji (*Freiberger Forschungsh.*, 1957, (**B16**), 35–49) The author presents some improvements of his calculation method for the determination of rolling force and deformation resistance in hot and cold rolling and quotes a number of examples. The agreement between calculated and measured values of resistance to deformation and of the rolling forces is now excellent (12 refs).—T.G.

Analysis of the phenomena taking place in the rolling gap when spreading is involved Z. Wusatowski (*Freiberger Forschungsh.*, 1957, (**B16**), 49–57) The author reports on a new method of calculation that allows determination of the degree of deformation for any shape of cross-section taking into account the spreading of the material. The mean rolling speed for the same cross-section can also be found by this new method. Slip, forward slip, and upsetting can also be calculated. The method may also be applied to the calculation of roll pass design for continuous mills.—T.G.

Rolling forces and torque during rolling of bullhead passes with top and bottom roll pressure G. Juretzek (*Freiberger Forschungsh.*, 1957, (**B16**), 58–81) The rolling forces during rolling of bullhead passes with alternating top and bottom roll pressure were studied on steel and lead. The results of the experiments were evaluated and are presented in many graphs. The knowledge gained from these results is of great importance for rolling practice and is discussed.—T.G.

Prestressing of rolling mill housings P. Ortner (*Rev. Mét.*, 1960, **57,** April, 311–317) A translation of an article from *Klepzig-Fachberichte*, 1958, **66,** 11. It is shown that prestressing of the roll stands does not reduce deformation, and shortening the stands brings no advantages, due to the flexibility of the rolls. Short barrel lengths, heavy roll necks, and a roll material with a high Young's modulus are all advantageous.

The development of blooming and billet mills M. L. Zaroshchinskii (*Stal'*, 1960, (6), 523–530) A world review of the development of the universal slabbing mill during the last ten years with a discussion of trends for the future (20 refs).

The development trend of continuous billet mills E. A. Zhukevich-Stosha and O. P. Solov'ev (*Stal'*, 1960, (6), 530–534) Continuous mills with alternate horizontal and vertical stands are advocated. Mills with horizontal stands and edging roller guides are only suitable for limited outputs and restricted rolling programmes. British and American mills are considered.

Case study in the rolling of steel bars S. Eilon and B. Avi-Itzhak (*J. Mech. Eng. Sci.*, 1960, **2,** June, 120–128) The effect of bar cross-section variation on length variation in the rolling of steel bars is discussed and the distribution of bar lengths as a function of the inlet to outlet cross-sections has been studied. It was found that this ratio is virtually independent of input length. The length ratios distribution and its parameters facilitate process adjustment by an appropriate selection of billet size in order to obtain a desirable mean bar length.—T.G.

Rolling high speed steels in square grooves P. P. Zuev (*Metallurg*, 1960, (4), 30–31) A scheme introduced by the operatives at the 'Elektrostal' ' blooming mill for rolling high speed steels in grooves: rhomb, rhomb, oval, circular rhomb, and rhomb grooves is explained. Blooms are reduced from 85 mm to 40 mm dia.

Quick change of continuous rod mills G. Leder (*Stahl Eisen*, 1960, **80,** Aug. 4, 1084) In order to save time, whole stands of a continuous rod mill are exchanged instead of only the rolls. The exchange takes about 5 min when specially developed hydraulic equipment is employed.—T.G.

Calculating the structure of the models for the finishing circular groove M. L. Mirenskii (*Metallurg*, 1960, (4), 31) The article which appeared in *ibid.*, 1959, (10), is criticized. The scheme of calculation given by the authors of this article, Konovalov and Chaban, does not apparently give precise results and the reader is referred to an article in *Stal'*, 1957, (1), by Mirenskii.

Technical and economic results of the production of lightened joists and channels in the rolling mills of the Kuznetsk Combine L. Ya. Kats and V. N. Ershov (*Stal'*, 1960, (7), 650–654) The economics of rolling lighter sections are set out.

Special features of rolling lightened sections, girders and beams G. D. Feigin and N. G. Nefed'ev (*Metallurg*, 1960, (2), 26–27) The various defects and mishaps generally occurring when rolling these sections, for example, the distortion of the shape due to cutting etc., are analysed and suggestions made for their avoidance.

Investigating the operation and the safety margins of 500 and 400 hot rolling mills L. D. Sokolov, V. M. Grebenik, I. L. Baklushkin, I. N. Veksin, V. I. Lyulenkov, V. P. Sabantsev, and A. P. Sobolev (*Izvest. VUZ Chern. Met.*, 1959, (11), 133–142) A theoretical investigation of the sections of the greatest loads in the 500 and 400 mills.

New greases for the cold rolling of sheet I. K. Tokar' and I. A. Chamin (*Metallurg*, 1960, (4), 28–29) Experiments at the TsNIIChM have demonstrated that rapeseed oil, castor oil, or beef and mutton tallow can with advantage replace palmitin, and also that they are superior to palmitic acid in their effect on the rolling process. All greases consisting of beef and mutton tallow are especially suitable for cold-rolling, deep drawing, and for operations where a reduction of the coefficient of friction is desirable. Best results are obtained with an addition of 3–5% free fatty acids.

Two methods of rolling tinplate on the continuous five stand mill M. A. Leichenko (*Metallurg*, 1960, (4), 25–27) This is a comparison between the Russian and English practice of cold-rolling sheet from 2·25 mm to 0·25 mm thick in a rolling mill of five stands. An examination by the TsNIIChM Institute has shown that the English practice is superior and suggestions are made for appropriate changes in the Russian practice.

Rolling bearing tubes on a three high mill Yu. I. Vashchenko (*Metallurg*, 1960, (4), 32–34) A special installation at the Pervouralsk works is described for rolling 100–220 mm dia. bars of ShKh15 steel cut in the cold on the hydraulic press in the lengths required. The blanks are preheated in circular furnaces with rotating bottoms at 1130–1150° and 1150–1170° for 1 to 2 h 50 min according to dia.

The effect of the calibration variables in a Stiefel type piercing mill on the formation and shape of external spiral shaped blemishes formed during piercing V. Dědek (*Hutn. Listy*, 1960, **25,** (3), 243–252) The effect of changes in the roll setting, e.g. position of the mandrel and eccentricity, on the formation of blemishes spiralling around the tubes was investigated. The most important variable proved to be the length of the deformation zone subject to torsion. On diminishing it the tendency to spiral formation also diminished.—P.F.

Control of cooling beds and cooling-bed shears H. G. Vogelsang (*Stahl Eisen*, 1960, **80,** Aug. 4, 1067–1072) The electrical control of a cooling bed, the cooling-bed shears and the by-pass equipment for the shears of a rod mill, is described under the headings: General extension of the control equipment to the braking of the cut rod in the cooling bed, control equipment with analogue travel data, two more modern types with digital travel data, and a rod placing or positioning control. The advantages of the digital control equipment with transistors, i.e. without the use of mechanical contacts, are pointed out.—T.G.

Optimizing the shearing of steel bars S. Eilon (*J. Mech. Eng. Sci.*, 1960, **2,** June, 129–142) The author deals with the problem of scrap and waste incurred in the shearing of steel bars and with the effect of bar length variability on the scrap function. The treatment is essentially mathematical.—T.G.

Experience with the shearing of pipes by rupture with local induction heating V. N. Bogdanov (*Stal'*, 1960, (7), 634–635) A system for use with high-speed continuous mills in which a clamp travelling with the pipe pulls it apart at a narrow induction-heated annular section.

MACHINERY AND SERVICES FOR IRON AND STEEL WORKS

Durgapur makes steel—The electrical group (*Brit. Steel.*, 1960, **26,** June, 173–174) The electrical equipment and distribution are described. Data of the mill motors are given.

Tongs for gripping thin sheet coils E. M. Vertoprakhov (*Metallurg*, 1960, (2), 32) Special tongs designed and constructed at the Magnitogorsk Metallurgical Institute are described. They are used on cranes for transporting coils of sheet. A diagram is shown.

Some maintenance aids for steel mill rotating equipment J. H. Greiner (*Blast Furn. Steel Plant*, 1960, **48,** June, 584–585) Several examples of easy access and replacement are given.

Motor-braking methods for steel plant applications J. C. Ponstingl (*Iron Steel Eng.*, 1960, **37,** April, 139–150) Various braking systems are described, and details and circuits are given of several countertorque, dynamic, and regenerative systems.

The Margam critical pressure back-pressure power plant (*Steam Eng.*, 1960, **29,** July, 346–357) With a list of sub-contractors.

Problems connected with the electricity supply grid in integrated iron and steel works H. Engelhardt (*Stahl Eisen*, 1960, **80,** July 21,

1000–1006) The difficulties encountered in keeping frequency and voltage constant in integrated iron and steelworks are considered.

WELDING AND FLAME-CUTTING

Welding and cutting technique in repair work in iron- and steelmaking practice W. Becker (*Iron Steel*, 1960, **12**, April, 199–210) A general review, with examples, of repair welding of cast iron and steel parts, flame and powder cutting, etc. (37 refs).

Choosing welding and cutting fuel gases to fit the need H. Thomasson (*Canad. Metalw.*, 1960, **23**, May, 38–39) The properties of gases used in welding, brazing, and cutting are briefly reviewed.—T.G.

Welding of heated cast iron parts with the back-fire-proof torch H. Neumann (*Schweissen Schneiden*, 1960, **12**, May, 233–235) The welding of preheated cast iron parts with the oxy-acetylene torch is described. Preheating of the parts is a necessary requirement for satisfactory welding, this in turn demands a safe torch which will not back-fire.—T.G.

Welding and connected techniques in the maintenance dept. of a large metallurgical plant L. Bonnier and M. Doncourt (*Soudage*, 1960, **14**, March–April, 131–140) Maintenance, repair and reconstruction work in the two shops of SOLLAC Continuous Rolling Co., at Sérémange and at Ebange, between Hayange and Thionville, are described, with particulars of welding and allied processes in use.—S.H.-S.

Welding problems in the chemical industry H. Gerbeaux (*Soudage*, 1960, **14**, March–April, 107–115) A review of special arrangements for welded tanks and silos, with advice upon details of assembly. The effects of superheating, hardening, and residual welding stresses, and of working, ageing, and heat-treatments upon the materials used, are discussed from the metallurgical view-point.—S.H.-S.

The use of oxy-acetylene pressure welding in the construction of a reinforced concrete road bridge W. Kniewasser (*Schweissen Schneiden*, 1960, **12**, May, 208–209) A small, transportable welding machine for the oxy-acetylene pressure welding of the joints of the reinforcement rods of a road bridge in the Alps is described. By using this welding machine considerable savings in construction time were obtained.

Recommended practice for flash welding. Part II. Hard carbon steels and alloy steels II W, Commission III (*Soudage*, 1960, **14**, March–April, 104–106) A code of practice and procedure is recommended for flash welding high carbon steels and low alloy (high speed) steels, and for high alloy (more particularly stainless) steels.—S.H.-S.

Some metallurgical aspects of welding greater thicknesses J. Sebille (*Rev. Soudure*, 1960, **16**, (2), 55–101) This article discusses the problem of welding greater thicknesses of steel which is becoming more complex with the present trend towards welded construction. The choice between and characteristics of welding processes in the light of the various factors involved are outlined. A detailed account of the problem of avoiding brittle fracture is given, illustrated by examples of the various defects.

Puddle-welding stainless steels M. Neal (*Mach. Lloyd*, 1960, **32**, June 25, 19–21) The Argonare fusion spot welding process as used by the Bristol Aircraft Co. is described.

Electroslag welding is the most progressive and efficient method of jointing thick metals B. E. Paton (*Rev. Soudure*, 1960, **16**, (2), 153–163) [In English] This article describes with examples the development in the USSR of electroslag welding which greatly increases the efficiency of welding greater thicknesses. It is claimed that its use in the USSR will be more than doubled during the next seven years.

Faults occurring in repair welding and their avoidance K. Weber (*Schweissen Schneiden*, 1960, **12**, May, 229–233) The welding techniques for the repair of cast-iron and cast-steel structural parts are described and illustrated In many cases correct heating of the part—or at least the neighbourhood of the defect—and very often a heat-treatment after welding are the key for a satisfactory weldment.—T.G.

Rolling and welding type 430 M tubes to stainless steel overlaid carbon steel tube sheets R. W. Bennett (*APAE–Memo–175*, 1959, Feb., pp.60; from *US Govt. Res. Rep.*, 1959, **32**, Oct. 16, 539) (No abstract).

Problems related to the home production of fluxes and wires for submerged arc welding and surfacing J. Wegrzyn (**Przeglad Spawalnictwa*, 1957, **9**, (3), 82–84) Fluxes discussed are: Mn-free (acid and alkaline) Mn-containing; and the application of fluxes with and without fluorite. Flux and welding rod manufacture are reviewed, with reference to Polish practice.

Three new welding products (*Soudage*, 1960, **14**, March–April, 124–125) A summary of preliminary information on (*a*) aluminium–bronze electrodes, (*b*) magnetic vices, and (*c*) mobile forced ventilation assembly 'Cyclone 60'.

Designing for welding K. G. K. Rao (*J. Inst. Eng. (India)*, 1959, **39**, Jan. Part I, 495–510) A careful consideration of the purposes of welding and choice of materials and of the strength of welds, with consideration of choice of welding procedure, residual stresses, and fatigue properties.

Welding jigs in structural steelwork A. Coblenz and R. Oswald (*Schweissen Schneiden*, 1960, **12**, June, 262–266) This is an illustrated description of the application of simple jigs in structural welding, including one for the welding of cooling boxes for blast-furnaces.—T.G.

Application of TTT diagrams to welding practice R. Müller (*Schweissen Schneiden*, 1960, **12**, July, 309–317) By plotting the cooling curve that is to be expected of a weldment into the *TTT* diagram, hardness and microstructure of the heat-affected zone might be predicted. These values are related to root cracking. The practice of this test is explained on a number of weldments.—T.G.

Influence of sampling, electrode type and welding conditions on the hydrogen content of the welded material H. Zitter (*Arch. Eisenh.*, 1960, **31**, June, 359–364) Test welds were made in a water-cooled copper mould to obtain reproducible conditions and prevent diffusion of H_2 through the work. A slight influence of welding current strength, and a marked increase of H_2 content in the weld bead due to electrode moisture were found and no influence of electrode coating was detected. A noticeable difference was found however, in the tendency of various coatings to take up moisture, given the same pretreatment (30 refs).

Tests for the determination of the weldability of steel F. Calvo (*Schweissen Schneiden*, 1960, **12**, July, 303–308) The author suggests a wedge test for the determination of the weldability. A bead is deposited by arc welding on the wedge and the weldability can be deduced from the structure, it is also reported that the transformation pearlite–austenite–martensite inside a pearlite grain starts in the martensite regions.—T.G.

The strength of weld-metal deposits and its interpretation in terms of modern theories of metal plasticity W. Dannöhl (*Schweissen Schneiden*, 1960, **12**, July, 297–303) The author discusses the problem of the increased proof stress of weld-metal deposits and of the weldments in general and attributes the increased strength to lattice distortions and dislocations. The increase of the lattice parameter of the iron lattice by additions of Mn and Mo and its decrease by Si addition are of particular interest to welding (14 refs).—T.G.

Development tendencies and weldability of modern steels for boiler, container and chemical plant construction K. L. Zeyen (**Industrie-Anzeiger* 1958, **80**, June 27, 739–743) Characteristic difference between a number of high-strength structural steels are discussed, their weldability is verified experimentally, and the need to use suitable welding rods emphasized (20 refs).

Improved weld inspection methods: magnetographic method I. E. Neifel'd and A. S. Fal'kevich (*Svaroch. Proizv.*, 1959, (2), 19–21) Pipeline butt welds were inspected with apparatus previously described and findings and improvements made in the apparatus since 1955 are considered. Combined magnetic and X-ray examination of all rejects is advocated.

Graphite cloth heating element instrumental in high speed brazing of stainless honeycomb panels (*Indust. Heat*, 1960, **27**, March, 492–296) A production time of approx. one panel per h, instead of 23 h with conventional methods, for materials such as 17–7 PH, is estimated. The parts are heated to 1680°F in A between two sheets of graphite cloth. Only the panel is heated; hence power is reduced, and tooling costs are less.—K.E.J.

A welding conference at Metz. I. Point of view of specifications J. Leclerc (*Soud. Techn. Connexes*, 1960, **14**, May–June, 179–181) This paper is a summary of suggestions made by the Commission of Heavy Ironworks regarding the bases for specifications of welded steels. **II. Conditions imposed on steelworks by the requirements of specifications** F. Pichon and F. Bourdillon (182–185) Problems encountered during production of steel to specifications are dealt with. **III. Guarantees of non-brittleness of structural steels within a specification** E. de Kerversau (186–192) A criterion for evaluating the sensitivity of a steel to brittle fracture is suggested. The relation between transition and service temp. is discussed. A new specification is suggested from practical considerations (12 refs.)—R.P.

A suitable method for welding sulphur cast iron P. S. Elistratov (*Svaroch. Proizv.*, 1960, (1), 36–37) Different electrodes are recommended to obtain specific structures with definite physical and mechanical properties from which the operator may select the most suitable.

Welding in a carbon dioxide atmosphere of 30 KhGSA steel in the quenched condition K. V. Lyubavskii, V. M. Nikitin, and G. F. Murov (*Svar. Proizv.*, 1960, (1), 4–6) All the experimental heat cycles decrease the hardness of the affected zone of the quenched section and increase its impact strength. In three experimental alternative heating cycles the heat-affected zone remained constant, which may be explained by the fact that the temp. of the metal in the welding zone produced by the flame is below that of the metal in the same zone produced by the welding arc.

Monel electrode welding of cast iron and steel V. Ilie (*Met. si Constr. Masini*, 1960, (1), 62–64) Grey iron components can be satisfactorily welded to steel with monel electrodes without formation of cracks. Preheating to 100–150° for essential pieces is advisable, with short duration welding at suitable intervals. All deposited metal to be forged. If the weldment has to be worked on the seam, it should be normalized.

Welding EI 712 (12Kh2NVFA) steel F. E. Tret'yakov and E. Yu. Freidlina (*Svar. Proizv.*, 1960, (5), 36–37) This steel in the quenched or normalized condition welds well with the manual arc process, argon-arc or automatic welding in an argon or CO_2 medium and does not require subsequent heat treatment. The welding may be carried out with or without metal deposition.

Bath-arc welding of flanges in a carbon dioxide medium A. I. Akulov and V. V. Spitsyn (*Svar. Proizv.*, 1960, (2), 31–32) The Bauman welding laboratory at the Moscow high school jointly with the Lyubertsi works have evolved a method of bath-arc welding in CO_2 of circular flanges of low carbon steel, 400–520 mm in dia. and 25–32 mm thick. Width of the butt is 60–70 mm. An existing carrier has been reconstructed and the operation is now speeded up by a factor of 10, yielding at the same time better quality joints.

Welding horizontal seams on thick metal in carbon dioxide gas V. N. Suslov and S. I. Klepikov (*Svar. Proizv.*, 1960, (3), 6–8) It has been established that in welding horizontal joints in CO_2 a good fusion in the vertical plane of the root face and the base metal is ensured by keeping the angle between the edges not less than 50° and the gap between the metals 4 mm. The minimum tempering heat to give good mechanical properties is 550°. Great care must be taken to ensure that the edges are properly cleaned and free from slag.

Welding recommendations for SAE and AISI steels H. Thielsch (*Canad. Metalw.*, 1960, **23**, May, 40) Electrodes, preheat, and interpass temp., and postheat treatment for stress-relief for SAE and AISI steels are presented in the form of a table.—T.G.

Welding aluminium, copper and stainless

steel with ultrasonics J. B. Jones (*Met. Prog.*, 1960, **78**, July, 117–120) It is shown that ultrasonic welding methods can be used to join materials with a wide range of properties, dissimilar metals such as Cu, Al, and stainless steels in bimetal combinations, and thin foils and fine wires.

Welding steel components with induction heating G. V. Klyushin (*Svar. Proizv.*, (5), 39) It is well known that in the induction heating of a two-layer medium consisting of an external layer having a greater specific resistance and a lower magnetic permeability than the inside layer, the maximum current density and therefore the maximum generation of heat will not be on the surface but in depth at the butt ends of the separate layers. This is precisely the case with induction heating of coaxial steel shafts or cylinders. Generators with a 500 c/s frequency weld at approximately 15 mm depth, those with 2000 c/s at approximately 10 mm and those of 8000 c/s frequency at about 5 mm.

Welding solid-fuel rocket motor cases P. J. Rieppel (*Met. Prog.*, 1960, **78**, July, 105–110) These thin-walled shells made of notch sensitive high-strength steels require satisfactory welding techniques; recommendations for welding are given.

The automatic facing (welding) of steel with copper wire electrodes S. M. Katler and V. A. Simkov (*Svar. Proizv.*, 1960, (3), 3–6) The possibility of arc welding copper on low carbon steel under flux has been demonstrated earlier. The characteristics of the fusion of the copper electrode and of the weld metal which forms as a consequence are here considered. The Fe–Cu alloys (with not over 10%Cu) applied by deposition on the steel surface may be of interest for increasing the wear resistance of mechanisms operating in granulated materials. The Fe–Cu alloy with over 80%Cu, owing to its high resistance to erosion, may be used for extra contacting surfaces of steel fittings such as taps, valves, flanges, etc.

Projection welding of components made of alloy steels and titanium F. E. Tret'yakov, A. B. Karan, and G. P. Tsar'kov (*Svar. Proizv.*, 1960, (3), 35–37) The process of welding anchor nuts, connecting pipes, sockets, etc., is described, including the preparation of the pieces for welding of the electrodes and the method suitable and the process of correcting defects.

Electro-slag welding of sulphur cast iron Yu. N. Zaitsev, A. M. Rogalov, and B. A. Kozlov (*Svar. Proizv.*, 1960, (5), 29–32) This type of welding may be used with advantage for parts 30 mm thick and over for the purpose of repairing casting defects and damages and for the production of welded-cast components. It may be carried out with electrodes of large cross-section or with 'consumable tips' made of cast iron. The use of steel wires as 'consumable tip' electrodes necessitates an increase in the content of graphitizers in the welding bath. The most suitable fluxes for welding sulphur cast iron have been found to be those containing fluorides.

Welding up openings by the electro-slag method V. D. Rozhko (*Svar. Proizv.*, 1960, (5), 38) The welding up of openings by the electro-slag method can be completed in one-quarter to one-sixth the time taken with manual arc welding, the consumption of flux is reduced by a factor of 15–20 and that of electrical energy by a factor of 1·5 to 2. The quality of the welds is very good.

Electro-slag welding of thick 1Kh18N9T steel sheet I. D. Davydenko, V. F. Koshevoi, and A. I. Nosenko (*Svar. Proizv.*, 1960, (3), 23–27) In preliminary experiments it has been established that electro-slag welding of parts made of this steel is possible and the joints show high resistance to intercrystalline corrosion. No hot or cold cracks were observed in all the alternative methods of welding. The best results however were given by the wire electrode Sv–1Kh18N9T with the 48–OF–6 flux.

Methods of applying ultrasonic vibrations to the welding bath A. A. Erokhin and L. L. Silin (*Svar. Proizv.*, 1960, (5), 4–7) Under real conditions of operation, ultrasonic vibrations can be transmitted to the welding bath through the metal being welded, by the contact of a heat-resistant or cooled end of a holder or device with the bath or through the wire of the electrode metal which is fed to the bath. An efficient way is by actual contact of the source of vibration with the bath, a method explained in this article. A suitable tape-electrode holder is shown in a diagram and experimental results have proved satisfactory.

Vibro-arc deposition under flux V. B. Shlyapin, Yu. G. Vinogradov, D. V. Leont'ev, and E. D. Lonskii (*Svar. Proizv.*, 1960, (2), 24–26) The operation is carried out with the TsNII–MA 5 automatic machine fitted with a mechanical vibrator of cam type, holding the electrode. The feeding rate of the electrode wire is adjusted by sets of interchangeable gears from 28 to 168 m/h and the frequency of vibration may be varied from 6 to 48 per sec. The amplitude of the vibrations can also be adjusted from 0·5 to 9 mm. The suggestion is made that this method may be used with advantage for repairing the eroded parts of machine components operating under repeated variable loads.

New ceramic flux for welding on deposits L. G. Livshits and A. I. Shiryaev (*Svar. Proizv.*, 1960, (1), 28–29) A new type of flux prepared in the laboratory is described: the components Flux AN–348 A or slag crust, 75% quality Fe–Mn and fluorspar are crushed separately on the ball mill and sieved through 0·02 mm mesh, iron chips are heated to 300–350° to burn off oil and organic particles. The fines and large particles are sieved through 0·25 and 2 mm meshes. The proportions are AN–348 A flux or slag crust 35–55%; iron chips 40–20%; Fe–Mn 15%; fluorspar 10%; waterglass (1·44–1·52 sp.gr.) 25–30% by weight of the dried mass.

Ceramic flux for automatic welding of stainless 1Kh18N9T steel *D.* M. Kushnerev and M. P. Grebel'nik (*Svar. Proizv.*, 1960, (5), 1–4) Type K–8 ceramic flux has been worked out based on the slag system CaO–MgO–TiO_2–Al_2O_3–CaF_2, with predominantly basic oxides. Due to the absence of easily reducible oxides in the flux and to the deoxidation of the welding bath by Si, no intensive oxidation of Cr and Ti takes place, thus ensuring low O_2 content in the weld metal.

Electrodes for welding type 347 stainless T. J. Moore (*Met. Prog.*, 1960, **78**, July, 93–100, 162–163, 166) Difficulties of welding 18–8 Nb-stabilized steels are discussed, and an investigation is described in which it is shown that a choice between five types of electrode may be made with satisfactory results, depending on temp., environment, and other conditions of service.

Electrodes with a plastic mass coating for gas shielding for welding low carbon and low alloy steels A. G. Mazel', E. M. Rogova, and L. I. Sorokin (*Svar. Proizv.*, 1960, (5), 25–28) A new type of welding electrode is suggested with a plastic mass coating in which instead of waterglass as binder, pitch is used. dc and ac electrodes have been evolved ensuring high efficiency and good mechanical properties.

Filler-rod for the gas-welding of s.g. iron R. H. T. Dixon and B. R. Thorneycroft (*Found. Trade J.*, 1960, **108**, May 12, 583–589) The authors describe the development of an Al- and Ni-bearing s.g. iron filler-rod with good deposition characteristics and weld-metal properties for use in the oxy-acetylene welding of spheroidal graphite cast irons. The Al contents vary between 0·05 and 0·5%, those of Ni between 1 and 5%, the rods contain otherwise approx. 3·7%C, 2·5%Si, 0·1%Mn, and 0·08%Mg. The weld joints have a consistently high level of mechanical properties (12 refs).

New chemical composition of chromium–nickel niobium austenitic welding wire Z. I. Kopel'man-Serpukhova, V. V. Ardentov, and N. P. Komarova (*Svar. Proizv.*, 1960, (2), 27–29) For the automatic deposition of an anti-corrosive surface layer a Cr–Ni–Nb wire of the following composition may be recommended: 0·05–0·10%C; 18·5–20·5%Cr; 1·8–2·2%Mn; 9·0–10·5%Ni; 0·2–0·45%Si; 0·9–1·3%Nb; and not over 0·03%P and 0·02%S. The deposited metal of this composition is not subject to hot cracks or to flaws related to intercrystalline corrosion (in the original state and when tempered at 670°) and in addition shows a smaller tendency to coarsening.

The nature of the metal deposit from coated electrodes (investigations with probes) A. N. Bykov and A. A. Erokhin (*Svar. Proizv.*, 1960, (2), 9–12) It has been experimentally established that the period of welding passes depends on the current strength and hardly changes on varying the thickness of the coatings from 1·3 to 1·7 mm. The time taken for deposition with a current above 180 amp. does not depend on the weight ratios of the coatings.

Investigating the welding of 15DXGS casting steel V. I. Klementov (*Svar. Proizv.*, 1960, (1), 9–13) With an increase in the linear energy from 3·7 to 12·7 kcal/cm on the hardness of the heat-affected zone diminishes considerably. An increase in the proportion of alloy elements calculated by carbon equivalent from C_{eq} 0·44% to C_{eq} 0·584% results in a steep increase in the maximum hardness of the zone under the rolls from 342 to 446 H_v (for a maximum rate of cooling). This steel may be welded with a cooling ratio of 8 degrees/sec. For a 50 mm thickness, the linear energy must not fall below 12–13 kcal/cm and for 18 mm, not below 6–7 kcal/cm.

Weld defects in austenitic stainless—cause and cure (*Met. Prog.*, 1960, **78**, July, 100–B) Seventeen examples of welding defects and their causes are described and illustrated by sketches in this data sheet.

The carburization of the weld metal in the welding of 1Kh18N9T steel I. A. Levin and V. A. Nikiforov (*Svar. Proizv.*, 1960, (1), 16–19) In the manual or automatic arc welding of this steel with electrode wire type SV–OKh18N9 or EI 606, independent of the carbon content in the wire, carburization of the welding seams takes place causing deterioration in their resistance to intercrystalline corrosion. The main source of carburization is the marble used in the coatings of electrodes and, in the case of automatic welding, the flux.

Strengthening the heat-affected welding zone of structural martensitic steels L. S. Popova and N. F. Lashko (*Svar. Proizv.*, 1960, (5), 11–15) The greatest increase in the strength of the softened section of the heat-affected zone is achieved by the complex alloying of the steel with V. In steels without V the hardness of the softened section amounts to 33 HRC while in those containing 0·26%V it reaches 42 HRC.

The melting of the electrode and the fusion of the base metal with manual arc welding A. G. Mazel' (*Svar. Proizv.*, 1960, (1), 13–16) Changes in the chemical composition and the surface of the bare electrode and the different coatings available make it possible to produce different nominal tensions in the arc. An increase in this tension is related to an increase of the work needed in the removal of the electrons from the cathode. Ares with high tensions and the same adjustment of the resistance of the welding machine melt the cathode more intensely than ares with low tensions. The intensity of the fusion of the anode does not depend on the tension but remains constant.

Problems in field welding chromium–molybdenum pipe R. L. Skaggs (*Met. Prog.*, 1960, **78**, July, 101–104) The importance of a correct preheating and post heating treatment in the site welding of the pipes of these air-hardening steels is emphasized, and techniques used are described. An account is given of the use of pre-formed thermite assemblies for stress relieving these welds.

Possibilities offered by the C.T.S. weldability test H. Granjon (*Rev. Mét.*, 1960, **57**, April, 319–326) The principle of the CTS ('controlled thermal severity') test is indicated and a report on tests carried out is made.

The effect of graphite on the gas content and porosity of seams welded under flux L. S. Sapiro (*Svar. Proizv.*, 1960, (3), 21–23) Graphite increases the H_2 content in welding under flux and reduces the O_2 and N_2 contents in the weld metal. In spite of the increase in H_2 in the welding bath the tendency of the seam to porosity diminishes. This may be due to the reduction of the activating effect of N_2 on the elimination of H_2 into the gaseous phase.

The effect of the ferrite phase on the resistance of austenitic welded joints to the formation of hot cracks M. Kh. Shorshorov, V. S. Sedykh, V. N. Zemzin, and A. E. Runov (*Svar. Proizv.*, 1960, (1), 1–4) The index of the resistance to

the formation of hot cracks (the critical speed of linear deformation) of the austenitic–ferritic weld metal depends on the proportion of the ferrite phase and on the nature of its alloying. Thus for weld metal 1Kh19N12M2F steel (with the KTI–5 electrode) an increase in the ferrite from 0 to 4–5% increases this index from 8 to 11–12 mm/min. A further increase in ferrite to 12% does not change the tendency to crack formation. For 1Kh19N9B steel (TsT–15 and ZIO electrodes) this index increases continuously from 3·6 to 11–12 mm/min with an increase in ferrite from 0 to 10–16%.

Aluminium-bronze welded fabrications. 2 M. Birkhead and C. V. Wilson (*Weld. Met. Fabr.*, 1960, **28** May, 198–205) Layering of mild steel with 9%Cu–7%Al alloy is described and structures are shown. Radiographic examination is dealt with. Uses are indicated.

Soldering stainless steels H. R. Brooker and W. J. Smellie (*Weld. Met. Fabr.*, 1960, **28,** June, 234) A letter raising questions about an article with this title by W. J. Smellie in the April issue. The original author replies.

Increasing productivity in the ship yard by flame cutting H. Koops and J. Bentfeldt (*Schweissen Schneiden*, 1960, **12,** June, 267–279) The authors describe the development of flame cutting during the last decade from the simple hand-operated torch to the most up-to-date electronically controlled flame cutting machine with special emphasis on raising productivity in the shipyard. The preparation of edges for subsequent welding by flame cutting and the savings in time effected by the application of this process are also considered.

Distortion problems in oxygen-cutting K. D. S. Semper (*Weld. Met. Fabr.*, 1960, **28,** June, 229–232) A review of various modes of distortion and methods of avoiding them.

Use of flame gouging in the repair of a kiln A. Buchholz (*Schweissen Schneiden*, 1960, **12,** May, 236–238) In the repair welding of a cast-steel journal of a kiln for the drying of lignite coal, flame gouging was employed in the preparation of the crack which was 2 m long. The wall thickness of the journal was 90 mm.

MACHINING AND MACHINABILITY

Cutting-force measurements on curve- and routing shears B. Leibinger (*Werkstattstech.*, 1960, **50,** June, 312–319) Cutting force measurements on curve- and routing shears showed that the forces are about twice as large as hitherto assumed. The measurements were carried out with strain gauges.—T.G.

Investigations on the surface deformation and the depth of penetration of the deformation in the machining of steel F. Lihl and H. Lawatsch (*Arch. Eisenh.*, 1960, **31,** March, 173–175) A radiographic method is described for the determination of surface deformation and its penetration as a function of cutting rate and depth, and feed.

Machining characteristics of leaded steel F. L. Bagley jun. and R. Mennell (*Trans. ASME J. Basic Eng.*, 1960, **82,** June, 347–357; *RPL* 23/6; *PB* 142078, 1959, Feb., pp.53) The effects of lead addition to alloy steel on the metal cutting process were explored over a wide range of conditions. In particular a range of cutting speeds (from 50 to 800 fpm) and workpiece hardness (from 230–450 Bhn) were investigated on one work-piece material (4340) using principally a carbide cutting tool. The conclusions are: (1) The effects of Pb on the cutting mechanism were revealed only below a critical speed which was found to decrease for increased workpiece hardness. The effects of Pb include decreased machining coefficient of friction, increased shear angle, decreased shear energy, and lower cutting forces below the critical speed. (3) An increase in cutting speed tended to decrease tool life more with leaded than with plain steel. (4) The lead additive acting as a lubricant on the chip-tool interface was found to be the mechanism whereby the above effects were produced below the critical speed. (5) It is proposed that the critical speed is directly related to the tool temp.

Phenomena occurring during cutting with knives H. Klemm (*Freiberger Forschungsh.*, 1957, **(B12)**, pp.81) The author distinguishes between cutting power and preservation of cutting power as the main criteria of cutting knives. The process of blunting of knives is studied and it is proposed to test them by pressing through a soft material such as lead. The pressure-cutting method has the advantage of straining the edge more than it is done in any other cutting test. The wear processes of knives have also been studied, as well as the effect of composition on cutting power, and on preservation of cutting power; the effect of hardness on cutting power is discussed besides many other points (28 refs).—T.G.

Manufacturing improvements in the fabrication of calibre .30 armour piercing cores D. E. Siefert (*Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308, pp.9) The advantages of decreasing the cycle time of the automatic screw machines and the crush form finish grinding of the form tools in the fabrication of calibre 0·30 in armour-piercing cores is discussed.—A.K.

Designing for easier machining and accuracy J. Kreitmeyer (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308, pp.5) The redesign of production methods and their application to several articles during manufacture are described. Results in terms of time and capital saved.

Applications and limits of the machinability test with increasing cutting rates: a short-time method for testing machinability H. Koelzer and K. H. Marten (*Werkstattstech.*, 1960, **50,** June, 301–304) The authors describe a short-time test for the appraisal of the machinability of a material which may replace the conventional machinability test. In the new test the cutting rate is continuously increased. The experiments reported are to show the relation between the new and the old method of testing. A number of steels were used for the tests ranging from mild steel to high-strength alloy steels. The limitation of the new test is that the results allow comparison to be made only within each group of steels, and that a generalization is not possible.—T.G.

Machinability testing and the use of the radiometric methods F. J. Daasch (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308, pp.17) Investigation of tool wear during machining operations using radioactive trace elements is discussed. The method is extremely useful for assessing cutting fluids and tool design.—R.D.

Routine machinability testing aids production R. F. Mennell (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308, pp.8) Machinability testing using a strain gauge dynamometer and an oscillograph recorder, to measure and record the principal forces on the cutting tool during machining is described.—R.D.

Status report on brittle cutting tool material W. B. Kennedy (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308, pp.6) The use of sintered Al_2O_3 cutting tools is discussed with reference to tool life, in relation to rake angle and resultant surface finish. Studies on brittle cutting tool materials to date show increasing promise.

Evaluation of physical and chemical properties of various carbide tool tips G. Underhill and F. J. Crowley (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308, pp.14) The determination of the following properties was made on each sample, composition, density, microstructure, hardness, grain size, carbide composition, together with the range of variation for each property. Metallographic examination is a valuable tool for quality evaluation of sintered carbide materials.—R.D.

Molybdenum and tungsten alloys E. J. Sandford (*Eng. Met. Design.*, 1960, **3,** March, 148–151) Recent progress is reviewed in the casting and sintering of various Mo and W alloys used for tools and cutting egdes. The article describes suitable metal working procedures for these alloys and gives details of several coating techniques for preventing oxidation of those alloys used in high temp. applications (16 refs).—A.T.

Damping cutting vibrations H. Frommelt (*Machinery*, 1960, **96,** June 1, 1241–1244) Milling studies on cast iron, steel, and high-Mn rail steel with carbide and ceramic tips are described. The use of copper-impregnated iron material for the shank was very effective in preventing vibrations.

Trepanning G. Hutson (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308, pp.16) Historical review, investigations, and progress to date on the subject of trepanning at Watervliet Arsenal is reported. British claims for a typical trepanning operation revealed a cutting rate of 6 in./min and speeds in excess of 700 ft/min compared with American methods of manufacture, giving 1·5 in/min and 0·50 ft/min using spade drills.—R.D.

Investigations on continuous and intermittent copying systems for turning machines W. Backe (*VDIZ*, 1960, **102,** May 1, 529) An abstract of a thesis, in which laws governing control of the systems, possible defects, and suggestions for improvements and increasing range of application are discussed.

Does the twist drill with special point offer any economic advantages in the drilling of grey cast iron? H. L. Hall, W. Grehn, and A. Wunsch (*Werkstattstedt.*, 1960, **50,** June, 305–309) When drilling grey iron castings with specially pointed twist drills, service life of the drill was longer by up to about 30% if the surface of the casting was prepared, and almost 100% for the as-cast surface, but the corresponding economic savings did not materialize as the new point is more expensive than the standard.—T.G.

Progress made in grinding and lapping of sintered cemented carbides B. Kleinschmidt (*Metall*, 1960, **14,** June, 567–569) The merits of synthetic diamonds for grinding, lapping, and honing of sintered cemented carbide tools are pointed out and illustrated. The use of correct binders for the wheels is also of great importance.—T.G.

Electrode materials J. L. Adcock (*Met. Treatment*, 1960, **27,** March, 103–112) The author surveys the range of suitable materials available for spark-machining electrodes and considers their relative merits in respect of cutting properties and low wastage. The paper is followed by an extensive and constructive discussion.—A.H.M.

Seizure in machine-tools J. Leonard (*Tecn. Met.*, 1959, **15,** Nov.–Dec., 229–243) In a review of present day knowledge of this subject, the author discusses four main instances of the process of seizure; micro-welding, fretting corrosion, irregularities in machining and finish, and the introduction of foreign matter. This is followed by a discussion of the influence of the structure and properties of the cast irons upon the problem.—F.S.

CLEANING AND PICKLING

Pickling 1200 tons of steel per week Stewarts and Lloyds Ltd (*Wiggin Nickel Alloys*, [1960] (56), 33–34) Monel equipment is used.

Complex unit for pickling sheet and strip R. M. Mantsev, G. R. Korotkov, A. S. Kaushanskii, A. A. Belyavskii, and A. K. Fisyun (*Stal'*, 1960, (6), 558–559) A brief account with diagrams.

Pickling before electroplating N. P. Fedot'ev and S. Ya. Grilikhes (*Electropl. Met. Fin.*, 1960, **13,** June, 217, 220; translated from a Russian book) Anodic and cathodic pickling are briefly reviewed.

Effect of halide addition to sulphuric acid pickling bath M. Haftel and W. L. Reichel (*ITL Test No.* 2896; *PB* 131794, 1957, Feb., pp.30; from *US Govt. Res. Rep.*, 1959, **31,** Jan. 16. 39) Effect of sodium halide addition in the range of 0·1 to 1% to inhibited H_2SO_4 pickling baths for mild steel and special treatment steel has been investigated.—S.H.-S.

Treatment of 1% carbon spring steel J. W. Mee (*Met. Treatment*, 1960, **27,** Feb., 45–49) An investigation into the effect of descaling prior to reheating for quenching on the decarburization, hardenability, and torsional fatigue properties of a carbon steel used for hot-formed springs is described, together with the effect of subsequent shot-peening. It is concluded that the removal of scale formed by the initial heating results in a decrease in the depth of decarburization and an increase in hardenability. If this is followed by shot-peening the fatigue limit is raised by 100%.—A.H.M.

Descaling and undercoating of alloy tubes in new installation at Wallingford Steel (*Indust. Heat.*, 1960, **27,** March, 542–548) Stainless and alloy tube is cleaned and coated to aid final drawing to close tolerances. The basic operations are immersion in a Kolene salt descaling bath, in H_2SO_4, and in Granodraw SS. The salt bath, operating at 900°F, has sludge settling pans which are removed during operation.—K.E.J.

The foundations of the production of high-class surface finishes T. Curti-Jung (*Metall-Reinigung+Vorbehandlung*, 1960, **9,** June, 87–90) The tools for obtaining high-class surfaces by polishing are briefly described.—T.G.

Surface conformation of metals under high nominal contact pressures L. H. Butler (*Metallurgia*, 1960, **61,** April, 167–174) To obtain a bright polished surface after such processes as wire drawing, strip rolling, impact, extrusion, etc., requires conformation between the deforming tool and the material without metallic pickup and scoring occurring. This article discusses the effect of lubricant characteristics and metal surface topography on the degree of conformation. It is shown that a thin semi-continuous lubricant film may easily be mechanically trapped at the tool to metal interface—the metal subsequently being deformed largely via fluid pressure. Such conditions lead to the production of a matt non-reflecting surface on the deformed material.

Recent trends in electro- and chemical polishing R. Pinner (*Electropl. Met. Fin.*, 1960, **13,** June, 205–214) Steel finishing, especially chromic acid treatments, are included.

Industrial electrolytic brightening of aluminium and steel S. Tajima (*Metalloberfläche* 1960, **14,** June, 177–181) After a brief historical survey the author discusses the advantages and limitations of electrolytic brightening in general and describes the plant required for the process on an industrial scale. In this part only details of Al polishing are given.—T.G.

Test methods for alkaline cleaner for conditioning treatment for acid cleaned cooling systems R. E. Wagner (*CCL* 72; *PB* 151727, 1958, Feb., pp.9; from *US Govt. Res. Rep.*, 1959, **32,** Sept. 1, 312) Methods of separation of PO_4, B_4O_7, and CO_3 ions were modified giving a precision of ~0·2%. The methods developed should be included in the military specification *MIL–C–10597 B*.

Shot blasting and subsequent mechanical cleaning of strip steel before cold rolling H. Höhle, H. Pannek, and W. Brinker (*Stahl Eisen*, 1960, **80,** July 7, 913–918) Experiments on the mechanical pickling of steel strip after hot rolling are described. Shot-blasting alone is not sufficient, acid pickling after shot blasting cuts down pickling time and acid consumption to a large degree. The use of ultrasound is effective only if the strip is given a surface pass before cleaning. The degree of reduction of this surface pass depends on the nature of the scale and on the degree of scale removal in the shot-blasting operation.—T.G.

PROTECTIVE COATINGS

Actual problems in the plating industry H. W. Dettner (*Metall*, 1960, **14,** June, 544–546) The author summarizes the existing problems in the plating industry with regard to improvement of the deposits, either with respect to better corrosion-resistance or to better decorative effects. In this connexion the importance of short-time corrosion tests is emphasized.—T.G.

Towards the automated plating process G. Saxby (*Met. Ind.*, 1960, **96,** March 4, 187–190, 192) The author deals in some detail with various aspects of the automation of the plating process. Chemical control systems are described together with automatic agitation by high-frequency sonic energy. X-rays can be used for measuring plating thickness while temperature control can be achieved using thermostatic methods and a motorized scanning switch.—A.H.M.

Macro- and micro-throwing power and levelling of plating baths E. Raub and A. von Krusenstjern (*Metall*, 1960, **14,** June, 521–524) The concepts 'macro-throwing power', 'micro-throwing power', and 'levelling' are explained and a number of examples quoted to elucidate them. A number of micrographs show the difference between true and false levelling.—T.G.

The adhesion of surface layers on metals H.-J. Engell (*Werks. Korros.*, 1960, **11,** March, 147–151) Relations between adhesion and surface forces are discussed, and departures from the ideal case to be taken into account in practice are reviewed, due to crystal structure, lattice defects and plasticity, and method of producing or bonding the surface layer (13 refs).

Finishes for protection against corrosion A. Elliott and J. H. Dickson (*Product Fin.*, 1960, **13,** May, 54–61) A reprint of a chapter from the book 'Laboratory Instruments, their Design and Application'.

Porosity of plated coatings (*NBS Techn. News Bull.*, 1959, **43,** Sept., 161–162) Tests on the Ferroxyl and other methods and a discussion of the influence of gases on porosity are noted.

Adolph Plating, a mechanized job shop E. A. Blount (*Products Fin.*, 1959, **24,** Nov., 24–33) An account of a Chicago Company plating with Cd, Zn, and Cu.

Today's chrome plate finishes F. Giordano (*Product. Eng.*, 1960, **31,** July 4, 36–38) Improved duplex chrome and duplex nickel finishes for car bodies or fittings are compared with the ordinary types.

The effect of flow rate and current density on the electrolytic removal rate of iron and copper from a Watts nickel solution A. M. Max and M. L. Whitehurst (*Proc. Amer. Electropl. Soc.*, 1959, 181–187; discussion 377) The deposition of Cu in a Ni solution is controlled by the diffusion rate of Cu through the cathode film. It is unaffected by current density but increases with increasing flow rate of the solution. With continued deposition, the roughening of the cathode surface increases its surface area and hence the rate of deposition. Iron is not deposited below a critical current density but above this value increase in flow rate increased the rate of deposition. The conversion of iron to $Fe(OH)_3$ occurs under oxidizing conditions at pH > 3. The removal of copper and over a limited range, of iron follows a logarithmic decay curve.—A.D.H.

Magnetic properties of electrodeposited nickel and nickel iron films S. Magari (*Met. Phys.*, 1959, **5,** July, 160).

Hot-dip galvanizing (*Corros. Prev.*, 1960, **7,** Feb., 52–54; from *Metalloberflasche*, **12,** (11), 337–347) The principles underlying the protective action of a galvanized coating are discussed, and various conditions of use are considered. Post-galvanizing treatments, and the various applications of the process are reviewed.

Hot-dip galvanising E. Braaten (*Tek. Uke.*, 1959, **106,** Oct. 1, 789–797) Hot-dip galvanizing in Norwegian practice is described, and the use of the product in corrosive conditions is discussed. Metallurgy of the process is discussed.

The role of hot galvanizing in the fight against corrosion R. Souské (*Corros. et Anticorr*, 1959, **7,** Dec., 434–439) The quality of deposits of zinc produced on steel by hot galvanization derives, in the first place, from the care given to different operations used. Tests are described in order to evaluate the resistance of zinc deposits: (1) purity of Zn, (2) thickness of coating, (3) temp. of galvanization. Thickness of deposit particularly depends upon grades of Zn, temp. of galvanization, duration of immersion, and speed of shrinkage.—S.H.-S.

Future prospects of hot dip galvanizing H. Bablik (*Met. Bull.*, 1960, Zinc special issue, March, 57, 59, 61, 63) A brief review with estimates of future demands.

Galvanizing at Harvey's (*Corr. Prev.*, 1959, **6,** Oct., 53–55) The methods followed at the Woolwich Road plant of G. A. Harvey & Co. (London) Ltd., are described.—S.H.-S.

Zinc coatings on iron and steel: 5. Design considerations A. K. Parker (*Met. Fin. J.*, 1960, **6,** April, 131–133, 150) Size, shape, complexity, and similar factors affecting hot-dip galvanizing and also those affecting the life of the coating are discussed, with a note on welding.

Plating zinc on steel from pyrophosphate solution D. Povey and U. F. Marx (*Proc. Amer. Electrop. Soc.*, 1959, 70–75, discussion 363) A pilot plant investigation of the electrodeposition of zinc from a bath containing $Zn_2P_2O_7$, $3H_2O$ 80, $K_4P_2O_7$ 300, potassium citrate 15 gm/l. at 55°C is described. Optimum operating conditions are given, and compared with those for zinc cyanide baths. The pyrophosphate bath will probably be cheaper to operate than the cyanide.—A.D.H.

Improved tinplate production technology G. F. Chub (*Stal'*, 1960, (5), 457) A note from Zaporozhstal'. Sn temp. was raised to 350°C increasing production by 4%, but as greater thickness was thus deposited an experimental roller and brush machine was tested. Other topics, including the use of tracer isotopes for Sn thickness gauging, are mentioned.

Aluminizing components of sulphur cast iron F. L. Al'ter-Pesotskii (*Metalloved. Term. Obra. Met.*, 1959, (12), 51–52) A process of Al coating is described giving a thickness of 0·3 mm with satisfactory results.

Aluminizing of steels (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 7) During the year several samples were aluminized for service trial such as auto-muffler parts, articles of post and telegraph pole line hardware and plumbers hardware samples. A good measure of success was achieved.

Aluminizing of stainless steel (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 7) Stainless steel samples were aluminized to obtain scaling resistance for high temp. applications. Heat resistance tests at 800°C were carried out with satisfactory results.

Dip aluminizing of steel wires K. Janecký (*Hutník*, 1960, **10,** (2), 61–64) [In Czech] Hot dip wire aluminizing processes are reviewed. For annealed wires the process is equivalent to hot galvanizing, and more economical. The high temp. of the Al-bath results in annealing; hard wires cannot therefore be produced by the method, as a re-draw would be required. This has not yet been solved technologically.

Deposition of copper on mild steel wire (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 12) Coils of mild steel wire were electroplated with bright Cu from an alkaline cyanide bath containing various brighteners. The coatings were bright and firmly adherent without any discontinuity even after drawing. A further series of experiments on electroless copper coating were conducted and uniform adherent coatings of copper were obtained varying from 0·0002 to 0·0003 in thick.

Levelling power of copper sulphate baths with addition of complexing agents E. Bertorelle, I. R. Bellobono, A. Scarati, and C. Bernasconi (*Proc. Amer. Electrop. Soc.*, 1959, 64–69; discussion 363) Determination of the effect of 0·001 M additions of organic reagents showed that no variation in crystal structure was caused even in the presence of those which have a pronounced effect on cathode polarization. Hydrogen overvoltage is considered to be an important factor in promoting levelling.

Chromium in cyanide solutions and its removal E. Laue (*Proc. Amer. Electrop. Soc.*, 1959, 188–194; discussion 377) The effects of chromate contamination of copper cyanide plating solutions are described and procedures for their removal by precipitation by mordant dyes, e.g. alizarin, are given.—A.D.H.

Electrophoretic deposition of metals, metalloids, and refractory oxides V. A. Lamb and W. E. Reid jun. (*Plating*, 1960, **47,** March, 291–296) Operating conditions are defined for the process. Conversion to practical coatings requires chemical reduction and sintering, further development being necessary before practical coatings are achieved. Coatings of Ti–Ni alloys on steel warrant further investigation.—S.H.-S.

Chemical conversion coatings R. F. Ayres (*Proc. Amer. Electrop. Soc.*, 1959, 81–92; discussion, 364–365) General principles of the production of conversion coatings on steel are discussed. The nature of phosphate coatings and their effect on surface roughness are investigated and the characteristics of chromate coatings are described.—A.D.H.

Conversion coatings. Chromate films L. F. Spencer (*Met. Fin.*, 1960, **58,** Jan., 58–65) The

structure, applications and properties of chromate films are described. The process is compared with phosphating.—A.D.H.

A new British Standard for phosphate coatings (*Met. Fin. J.*, 1960, **6**, April, 134–136, 150) A review of BS.3189:1959 and a comparison with DEF–29.

Surface texture: Its influence on organic finishing D. H. Lloyd and W. Stein (*Proc. Amer. Electropl. Soc.*, 1959, 104–112; discussion 366) The influence of steel surface finish on the smoothness of painted surfaces is discussed.—A.D.H.

Plastic coated steel S. S. Carlisle (*New Sci.*, 1960, **7**, Feb., 25 471–474) A general account.

Plastic on steel—PLATAL (*Werk und Wir*, 1959, **7**, Sept., 299–304) A description of the manufacture and properties of the plastic-coated sheet 'Platal' produced by Dortmunder Plastik G.m.b.H.

Built-in sales appeal pays off (*Iron Age*, 1959, **184**, Oct. 22, 202–204) The wide range of application of coated metals is listed. Production has increased 100-fold in five years and further expansion is predicted.—A.C.

Properties stand up to service under rigid testing (*Iron Age*, 1959, **184**, Oct. 22, 205–207) Details are given of physical properties and resistance to abrasion, moisture, chemicals, and staining.—A.G.

Improving the quality of chromium plating (*Sheet Met. Ind.*, 1959, **36**, Dec., 804, 807) Details of a new British Standard 'Electroplated Coatings of Nickel and Chromium' are given which includes provision for thicker coatings of Ni tests for corrosion resistance and tests to ensure that plated finish will not easily peel away. The article describes the new Mond Nickel labelling scheme for Cr plated products and the B.N.F. Plating Gauge for the determining of the thickness of electroplated coatings.—A.H.M.

Plating anodes D. J. Fishlock (*Met. Ind.*, 1959 **95**, Oct. 9, 177–180) The author gives examples where the use of an insoluble anode is required. Various types are described with special reference to Cr plating anodes. A useful table is given summarizing the recommendation in the choice of anodes.—A.H.M.

The effect of working conditions of a complex urea-bearing sulphate electrolyte on the composition of iron–chromium–nickel alloy deposits W. Machu and M. F. M. El-Ghandour (*Werks. Korr.*, 1960, **11**, July, 420–425) The working conditions for a Fe–Cr–Ni bath that gives deposits which correspond to that of stainless steel have been established. As the three metals impede each other in their deposition the cathode efficiency is very low and reaches 25% at the maximum. The phenomena occuring at the cathode have been studied in detail.

Wiggin nickel anodes for electroplating H. Wiggin & Co. Ltd (*Wiggin Nickel Alloys*, [1960], (56), 6–8).

Automatic pH regulation of nickel-plating solutions G. Gabrielson (*Met. Fin. J.*, 1960, **6**, June, 239–242) Effects of acidity variations are noted and the arrangement using a gears electrode for automatic adjustments is described.

Chemical nickel plating G. Fitzgerald-Lee (*Product Fin.*, 1960, **13** May, 68–70) A description of the Kanigen process.

Study of testing of galvanized wire after W. H. Preece D. Horstmann (*Stahl Eisen*, 1960, **80**, July 7, 931–935) Studies of the reliability and consistency of the Preece test for galvanized wire showed that it cannot be recommended for practical use.—T.G.

Occurrence of 'beard' structure and special features of the diffusion processes in the formation of iron–zinc layers in hot-dip galvanizing H. Bablik, F. Götzl, and E. Nell (*Arch. Eisenh.*, 1960, **31**, June, 331–336) The structure of a form of Zn coating differing from the usual structure of Fe–Zn coatings is discussed and termed 'beard' structure. This is caused by disordered distribution of individual ξ-crystals in a Zn ground mass. The mechanism of this formation is discussed.

Hot-dip aluminizing of steel wire and sheets (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 36–37) Laboratory scale tests have been successful and a pilot plant is being constructed.

Vapour plating by vacuum evaporation B. J. Williams (*Electropl. Met. Fin.*, 1960, **13**, July, 247–251) Cd deposition and the corrosion resistance and adhesion are discussed. Adhesion is improved by grit-blasting the steel surface.

Electrochemical measurements on the passivation of a steel with 18%Cr and 8%Ni A. Rahmel and W. Schwenk (*Arch. Eisenh.*, 1960, **31**, March, 189–193) Current-density time curves on passivated non-stabilized 18/8 steel showed the existence of a reciprocal current in density-time law, which was explained on the basis of the electrochemical formation of surface layers. Quantitative evaluation of the results gave passive layers of about 20–45 Å thickness. It is shown that the formation of these layers is due to processes related to nucleation and grain growth (20 refs).

New continuity test for phosphate coatings W. M. Kisner (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308, pp.11) Development of a reproducible test for phosphate coatings to replace the existing unsatisfactory tests is described. Results show a fairly good demarcation between the poorly coated and the satisfactorily coated samples, in contrast to the result obtained with the salt spray test.—R.D.

Direct application of cover coat enamel to steel S. E. A. Ryder (*Inst. Vitr. Enamel. Bull.*, 1960, **10**, June, 361–368) Reasons for dispensing with the ground coat and results achieved are indicated. Talysurf studies of the resulting finishes are shown.

Factors affecting the enamelling of cast iron baths A. W. Murdoch (*Inst. Vitr. Enamel Bull.*, 1960, **10**, May, 351–359) Casting defects, the thermal expansions of the metal and enamel, corrosion resistance, enamel opacity, surface finish, and causes of rejects are briefly reviewed.

Wettability of enamel–metal systems R. M. King and R. L. Cook (*Inst. Vitr. Enamel. Bull.*, 1960, **10**, Jan., 254–260) It was shown that ground coat and one coat Ti white enamels in a dry furnace atmosphere in the absence of Fe oxides did not wet iron surfaces. The effects of various amounts of Fe oxide and of furnace moisture on final contact angles are examined.

Blistering of wet process vitreous enamels on cast iron—some facts and theories E. R. Evans and A. D. Morgan (*Inst. Vitr. Enamel. Bull.*, 1960, **10**, Jan., 261–274) Theories of blister formation are reviewed, and evidence is put forward that the gases responsible are oxides of carbon formed by direct and indirect oxidation of C in the iron by atmospheric oxygen. Methods of minimizing blister formation are discussed.

Influences of hydrogen in vitreous enamelling of steel G. P. K. Chu (*Inst. Vitr. Enamel. Bull.*, 1960, **10**, Jan., 235–253) Sources of H_2 are discussed: initial H_2 content of the steel, water and OH-ions in the glass structure, combined water in enamelling clays and moisture in furnace atmospheres. The behaviour of H_2 is evaluated by cathodic charging and methods of eliminating H_2 and its effects are reviewed (40 refs).

Successful protective anticorrosive painting B. Söderlund (*Tekn. Kem. Aik.*, 1960, **17**, (7), 229–233).

G.E. installs giant flow coating system J. A. Kinn (*Products Fin.*, 1959, **24**, Nov., 34–39) An illustrated account of the new General Electric plant at Louisville operating at up to 30 ft/min and applying three coats 1 mil thick.

Method of testing the chemical resistance of internally varnished sample trays A. Werner (*Werks. Korros.*, 1960, **11**, March, 155–156) A method of testing the suitability of lacquer finishes for use in containers for transport etc.

Test of paints for water tank interiors J. D. Keane and J. Bigos (*J. Am. Water Works Assoc.*, 1960, **52**, May, 623–630) Tests lasting from Dec. 1950 to Sept. 1958 are reported. Vinyls performed well.

POWDER METALLURGY

The iron powder plant at Alan Wood Steel Co. J. W. Traub and K. W. Bruland (*Iron Steel Eng.*, 1960, **37**, April, 167–174) A description of this direct-reduction plant and its operating principles. The fluid bed 'H-iron' process is used, in which iron oxide is reduced with H_2 at below 1000°F, at a pressure of about 500 psi.

Powder metallurgical production of iron–aluminium wires E. Nagy (*Koh. Lapok.*, 1959, **14**, Nov., 493–498) The author describes Hungarian experiments on the production of 10%Al, 90%Fe alloy wires of minimum diameter 0·40 mm.—P.K.

Sensitivity of electrochemical potential to the degree of sintering B. Bovarnick (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308, pp.18) The electrochemical test as a means of determining the degree of sintering of iron powder has been investigated. Results were supplemented using metallographic examination. It is concluded that the techniques and findings of the experiments have very wide potential application both in the investigation of fundamental physical phenomena and to employment in engineering and industrial technology.—R.D.

Sintered iron-base alloys for machine parts. V. Properties of sintered iron–copper alloys. III T. Watanbe, Y. Fujii, and E. Hayashi (*Rep. Inst. Ind. Res. Inst. Nagoya*, 1958, **7**, Feb., 105–109) Quenched and reheated compacts single or double pressed were examined for precipitation hardening and tensile properties.

Vacuum sintering F. G. Cox (*Murex Rev.*, 1960, **2**, July, 41–61) Induction and other furnaces and their construction, vacuum gauges, and specific applications of the process are described, such as hard metals and the rarer metals.

Mass flow in sintering metal powders Y. Masuda (*Met. Phys.*, 1955, **1**, May, 101–107) [In Japanese].

The dependence of density, electrical resistivity and microstructure upon the process of sintering in Fe–Al–Ni Magnet alloy K. Shida (*Nippon Kinzoku*, 1959, **23**, April, 199–203) In the $FeAl_2$–Ni–Fe system (Fe 63, Al 12, Ni 25%), the resistance at 700°C falls to 1/26–1/58 of that in green compacts, suggesting that diffusion has set in. At 1250°C there is rapid alloying, and after 90 min. at 1350°C only α-phase is present. Compacting pressure has a greater effect when a liquid phase is absent than present, and sintering temp. has a greater effect than time.—K.E.J.

FERRITES CERMETS AND CARBIDES

Properties of manganese ferrites prepared at various oxygen pressures A. Braginski (*J. Appl. Phys.*, 1960, **31**, Supplement, May, 339s) Mn ferrite solid solutions $Mn_yFe_{3-y}O_{4+y}$, $0{\cdot}87 < y < 1{\cdot}14$ were investigated. Lattice defects formed during sintering and facilitated both the reduction of oxidation processes during cooling depending upon the oxygen pressure applied. The concentration of defects at constant sintering temp. increased with the iron content, especially at $y < 1$.

Studies on ferrites X. Microscopic structure of O.P. magnets containing $2FeO,TiO_2$; $2FeO,ZrO_2$; As_2O_3 and Bi_2O_3 T. Takei, M. Sugimoto, and T. Hishinuma (*Rep. Sci. Res. Inst.*, 1956, **32**, July, 106–111).

Ferrites and oxides S. Iida (*J. Appl. Phys.*, 1960, **31**, Supplement, May, 251s–258s) The kinetics of magnetic annealing effects in Fe–Co ferrites is studied based on a vacancy migration mechanism. A quantitative calculation of the annihilation process of the magnetic annealing anisotropy in isothermal annealing accords exactly with experimental results for Fe—Co ferrites. The equilibrium density of vacancies in Fe–Co ferrites is discussed. From a statistical study it is concluded that the decrease in the degree of oxidation simply makes the scale of the time constant of the relaxation process longer, therefore it is not consistent with the suggestion, previously made that only Co ions near vacancies can rearrange rapidly.

The $k\pi$ walls in ferrites M. Paulus (*Compt. Rend.*, 1960, **250**, Feb. 15, 1213–1215) It is shown that $k\pi$ walls composed of several walls at 180° are formed in ferrimagnetic materials.

The cermets (*Met. Treatment*, 1960, **29**, Feb., 60–62) The need for materials with good load-carrying capacity at temp. of 1000°C and upwards lead to the development of cermets

which are metal–ceramic mixtures. The article gives a brief historical note followed by a description of the sintering method of producing cermets. An outline is given of a newly developed method where molten metal and ceramics are flame sprayed in alternate layers, the mixture is then crushed and hot-pressed. Examples of the successful application of cermets are given which include lining of chemical reaction vessels, high temperature bearings, and protective sheating in atomic reactors.

Cermets of zirconia–iron series. II. Stabilization of zirconia with lime S. Naka, H. Matsumoto, and C. Noguchi (*Rep. Gov. Ind. Res. Inst., Nagoya*, 1955, **4,** June, 292–296) [In Japanese].

PROPERTIES AND TESTS

Development of materials testing on the German railways (1860 to 1927) R. Kühnel (*Materialprüfung.*, 1960, **2,** April 20, 134–139) The development of the materials testing organization of the German railways is described, commencing with the first fatigue tests of Wöhler, with reference to some specific problems (22 refs).

Improvement in the quality of ferrous and copper metals (*Usine Nouv.*, 1960, March, 13) A review of investigations made by Etabl. Merlin & Gérin relative to improvements in quality of steel, copper, brass, and bronze.

A simple laboratory furnace for temperatures of up to 3000°C L. Hinz and R. Brückner (*Elektrowärme*, 1960, **18,** May, 166–169) A resistance furnace using a tubular heating element of W with a rating of about 7 kW is described and illustrated. Temp. of 2800°C may be maintained over long periods and 3000°C may be reached. The uniform temp. zone is small, about 30 mm long, with a diameter of 20 mm.—T.G.

Physical and mechanical properties of nine commercial precipitation hardenable stainless steels D. A. Roberts D. B. Roach, and A. M. Hall (*DMIC Rept.* 112; *AD*–214, 194, *PB* 151068, 1959, May, pp.83; from *US Govt. Res. Rep.*, 1959, **32,** Sept. 11, 367) Steels tested include martensitic and austenitic types. Room and elevated temp. properties, and the effect of heat treatment on these properties are reported.

Properties of certain cold-rolled austenitic stainless sheet steels R. J. Mangone, D. B. Roach, and A. M. Hall (*DMIC Rept.* 113; *AD*–214845; *PB* 151069, 1959, May 15, pp.64; from *US Govt. Res. Rep.*, 1959, **32,** Sept. 11, 368) Information is given on the properties of five austenitic steels cold-rolled to the fully-hard and extra-hard conditions.

On the plastic deformation of steel M. Puebla Camino (*Inst. Hierro Acero*, 1960, **8,** Jan., 100–109) A review of the ways in which various materials such as plasticine have been used to study the mechanical deformation of metals, and the results of such studies, is given.—P.S.

On the Griffith–Irwin fracture theory J. L. Sanders jun. (*J. App. Mech.*, 1960, **27,** June, 352–353) The purpose of the present paper is to give a new mathematical formulation of the criterion for crack extension according to the Griffith–Irwin theory in terms of a path-independent line integral. The derivation will be made for the case of a crack in a plate where the plane stress theory applies but it may be generalized easily to other cases (three-dimensional elasticity, shells, etc.).

Effects of directional ordering on the damping of zone melted iron R. E. Maringer (*J. App. Phys.*, 1960, **31,** Supplement, May, 229s–230s) Damping measurements have been made as a function of temp. and time on zone melted high purity iron to which carbon or nitrogen have been added. Two main effects exist. These are a distortion of the Snoek peak and a time dependent decrease in damping which has been called the 'magneto-elastic after-effect.' Magneto-elastic after-effect data for zone-melted iron containing carbon have been analysed and shown to yield relaxation times in good agreement with those expected on the assumption that the effect is controlled by the interstitial diffusion of carbon.

Dislocation damping in metals D. H. Niblett and J. Wilks (*Advan. Phys.*, 1960, **9,** Jan., 1–88) A detailed review of internal friction at low, medium, and high temp. with discussion of the Bordoni peak and of amplitude-independent conditions at low-strain amplitudes with a survey of theory (125 refs).

Influence of a magnetic field on the damping of specimens of iron of varying purity F. Dubosi and J. Talbot (*Compt. Rend.*, 1960, **250,** March 14, 2025–2026) It is shown that displacement of the block walls has a considerable influence on damping.

Internal friction study of cold-worked iron containing nitrogen D. Petarra (*AFOSR–TN* 59–270; *AD* 212704; *PB* 142004, 1959, April, pp.31; from *US Govt. Res. Rep.*, 1959, **32,** Oct. 16, 497) A mechanism explaining the complex behaviour of 220°C peak height as a function of annealing temp. is advanced. The recovery process directly affects the height of the 220°C internal friction peak and indirectly the height of room temp. internal friction peak. The relationship is brought out.—S.H.-S.

Dislocations in metals L. Habraken (*Techn. Humanisme*, 1959, (60), **57,** (4), 5–28) A review of dislocation theory with illustrations and diagrams (14 refs).

The measurement of residual stresses J. Pomey (*Bulletin SFM*, No.27, (Editions Science et Industrie), pp.15, reprint) Various methods of analysis of residual stresses are classified and described.

Method for the detection of stresses in the individual zones of a hardening structure H. Borchers and A. Safferling (*Arch. Eisenh.*, 1960, **31,** May, 287–290) The method described consists in using sample plates quenched on two sides, and cut into small bars in directions parallel to the quenched surfaces. The stresses were determined from the elastic recovery of the specimens, and the results compared with the electro-acoustic results obtained by Kaiser's method (*ibid.*, 1953, **24,** 43–45).

The bearing properties of 1% C Cr steel as influenced by steelmaking practice R. F. Johnson and J. F. Sewell (*JISI*, 1960, **196,** Dec., 414–444) [This issue].

Rupture of silicon–iron sheets and related creep phenomena C. W. Chen (*JISI*, 1960, **196,** Dec., 385–389) [This issue].

Mechanical aspects of the brittle fracture of steels W. Soete (*Rev. Soudure*, 1960, **16,** (2), 165–194) A description of the causes of brittle fracture is given. It is concluded that the chance of the occurrence of brittle fracture is very slight in view of the extent of plastic deformation. A study is made of the behaviour of the defective piece. The most important problems remaining to be solved are: the capacity for deformation of a defective piece, the establishment of methods of heat treatment of steels so as to be able to use them in the most ductile condition, and the study of the effect of accumulated energy on the properties of brittleness.

Investigation into effects of carbon and nitrogen in temper brittleness in steels K. J. Stodden and J. W. Fredrickson (*WAL* 310/110–16; *PB* 134984, 1949, Nov., pp.76; from *US Govt. Res. Rep.*, 1959, **31,** Jan. 16, 39) Brittle failure in tension was not obtained for wire specimens having tempered martensitic microstructure, even when subjected to temper embrittlement and testing at temp. −190°C. Wire tensile specimens having tempered martensitic microstructure were notched circumferentially and tested in tension at from room temp. to −190°C. A plot of reduction of area at base of notch versus testing temp. revealed a transition from high ductility at higher temp. to lower ductility at reduced temp.—S.H.-S.

Embrittlement of alloy steel at high strength levels L. J. Klinger and W. J. Barnett (*WADC –TR* 53–205; *AD* 22974; *PB* 135418, 1953, July, pp.89; from *US Govt. Res. Rep.*, 1959, **31,** Feb. 13, 101) Embrittlement on tempering quenched steels to high strength levels is a precipitation or ageing phenomenon. A structure of 100% bainite is not subject to embrittling reaction. It is proposed that embrittlement arises from localized precipitation of cementite in prior austenite grain boundaries which precedes the general precipitation.

Hydrogen embrittlement relief of phosphated steel R. E. Bessey (*SA–TR* 18–1067; *PB* 140744, 1959, Feb., pp.12; from *US Govt. Res. Rep.*, 1959, **32,** Sept. 11, 368) Tests made on unphosphated steel, Zn- and Mn-phosphated steel, post-treated by low-temp. heat treatment and by room-temp. ageing as specified in *MIL–P–16232B* for relieving H_2 embrittlement of phosphated steel are not effective for this steel.

Friction characteristics of sliding surfaces undergoing subsurface plastic flow M. C. Shaw, A. Ber, and P. A. Mamin (*Trans. ASME, J. Basic Eng.*, 1960, **82,** June, 342–345) It is well known that the load of an ordinary friction slider is supported by a large number of surface asperities having a collective area that is small compared with the apparent area of contact. The metal in bulk beneath such surface asperities is elastically loaded. In many operations the bulk metal undergoes plastic deformation as sliding occurs. The influence of this subsurface flow upon the coefficient of sliding friction is discussed. A simple test procedure for studying the friction characteristics of sliding metal surfaces, one of which is being subjected to plastic flow in bulk is described, and representative data are presented for both dry and lubricated sliding.

The effect of ball bearing steel structure on rolling friction and contact plastic deformation R. D. Drutowski and E. D. Mikus (*Trans. ASME, J. Basic Eng.*, 1960, **82,** June, 302–308) The rolling friction, contact plastic deformation and elastic limit were determined for SAE 52100 steel structures with retained austenite contents from 0 to 18·4%. The force necessary to roll a ball on a plate decreased as the retained austenite was decreased. The contact stress necessary for the initiation of plastic deformation and the elastic limit of the material increased as the retained austenite content decreased from 18·4 to 3·9%. No further change occurred when the retained austenite was reduced to zero. The extent of plastic deformation at very high contact stresses was reduced by the presence of retained austenite contents up to at least 7·4%. These observations were used to select the best steel structure for an instrument ball bearing.

The significance of surface finish on friction wear and lubrication A. Sonntag (*Reprint from Seminar on Friction, Lubrication and Wear, Lucerne*, 1959, Sept. 17, pp.8) Surfaces and the measurement of surface roughness and its significance in frictional studies are discussed. Wear life was measured on sand-blasted test rings and blocks and the results are discussed (21 refs).

Lubrication by solids J. Gaensheimer (*Reprint from Seminar on Friction, Lubrication and Wear, Lucerne*, 1959, Sept. 18, also in *Indian Railway Engineer*, 1960, **7,** Jan., pp.8) Measurements of steel-on-steel friction in presence of MoS_2 and other lubricants are made and discussed with reference to surface form and the mechanism of lubrication (24 refs).

Contact area of rough surfaces I. V. Kragelsky and N. B. Demkin (*Wear*, 1960, **3,** May–June, 170–187) A proposed formula giving real area of contact and joint rigidity is advanced.

Friction and wear phenomena in seized pistons A. D. Haag (*Wear*, 1960, **3,** May–June, 219–234) [In German] Pistons jammed by thermal expansion have been examined showing that in spite of the oil film, mechanical damage to the surface occurs as soon as the local load is high enough, and electron microscopy shows that this is also the case in the submicroscopic region. Wear is therefore due to surface fatigue as well as to abrasion.

A replica method for examining wear and scuffing in cylinder liners A. P. Young and C. M. Schwartz (*Wear*, 1960, **3,** May–June, 235–240).

A magnetic study of some iron–nickel–aluminium alloys Wang Huan-yuan, Chang Shou-kung, and Pan Shiao-thur (*Acta Phys. Sin.*, 1960, **16,** April, 214–228) The tieline of the two-phase region $\beta+\beta'$ was followed.

Permanent magnets S. Shtrikman and D. Treves (*J. Appl. Phys.*, 1960, **31,** Supplement, May, 58s–66s) In studying the maximum remanence of random assemblies of aligned particles with various anisotropies the main assumption is that on removal of the field

after saturation the magnetization comes to that preferred crystal direction which includes the smallest angle with the previously applied field. The maximum remanence in any direction is discussed and a relation between its parallel and transverse components derived.

Coercive force and remanence of 25 Å to 2000 Å diameter cobalt, iron and iron cobalt alloy F. E. Luborsky and T. O. Paine (*J. Appl. Phys.*, 1960, **31,** Supplement, May, 68S–70S) This paper reports an experimental study of the size dependence of the coercive force and remanence of essentially spherical Co, Fe, and Fe–Co alloy particles over the dia. range from 25 Å to 2000 Å. The coercive force remanence and their temp. coefficients are discussed in terms of the approach to single domain behaviour, the anisotropy constants which determine single domain rotation and the transition to super paramagnetic behaviour. Crystal anisotropy predominates in the cobalt particles, a combination of shape and crystal in the iron particles and shape anisotropy in the iron–cobalt alloy particles.

Angular variation of the magnetic properties of elongated single-domain iron particles F. E. Luborsky and T. O. Paine (*J. Appl. Phys.*, 1960, **31,** Supplement, May, 66S–68S) The demagnetization curves of oriented elongated single-domain iron particles have been measured as a function of angle and packing fraction. The reduced coercive forces of dilute compacts show a maximum at an angle of about 50°, associated with a buck ing magnetization reversal. As the packing fraction is increased, particle magnetostatic interaction lowers the coercive force and suppresses the 50° max. The residual to saturation ratio appears as a distorted cosine function which the simple single domain particle model cannot account for without assuming particle orientations inconsistent with electron micrographs. A more realistic model is proposed.

Interpretation of the magnetic and crystallographic properties of several iron, nickel, and iron nickel nitrides J. B. Goodenough, A. Wold and R. J. Arnott (*J. Appl. Phys.*, 1960, **31,** Supplement, May, 342S–343S) The saturation moment at 4°K and the room temp. structure of various nitrides were examined. The atomic ordering, nitrogen solubility, and atomic moments of the system $Fe_{4-x}Ni_xN$ are interpreted from a model of the band structure of the f.c.c. transition elements of the first long period in which it is explicitly assumed that the crystalline fields split the d bands into separate components.

Magnetic behaviour in the transition region of a hematite single crystal S. T. Lin (*J. Appl. Phys.*, 1960, **31,** Supplement, May, 273S–274S) The magnetic behaviour in the transition region of a hematite single crystal from Elba has been investigated. The remanence-temp. relationship and the thermal hysteresis effect have been obtained for each of three mutually perpendicular directions of the crystal in the temp. range 488°–77°K. Experimental data show that the direction and magnitude of the remanent magnetization vector changes continuously between the [111] direction and the [111] plane when the temp. changes through the transition region.

The analysis of cementite in chromium steels by measurement of its magnetic properties W. Koch, W. Jellinghaus, and H. Rohde (*Arch. Eisenh.*, 1960, **31,** March, 183–188) A method is described for determining the Cr content of Cr-containing carbides is described, which depends on the relationship of the magnetic saturation properties and the Curie point to Cr content. Carbide changes in the transformation reactions in Cr steel are examined.

The induced magnetic anisotropy in evaporated films of nickel–iron alloys M. Prutton and E. M. Bradley (*Proc. Phys. Soc.*, 1960, **78,** April, 557–574).

Applying non-destructive test standards to improve product quality and reliability G. W. McDermott (*Gen. Motors Eng. J.*, 1960, **7,** April–May–June, 32–36) A brief review of methods; the classification of imperfections according to origin and assessment of their importance, and criteria for acceptance or rejection of parts are considered. A glossary of terms describing defects is added.

Magnetic analysis of an iron single crystal S. Yamaguchi (*Z. Metallk.*, 1960, **51,** June, 340–341) Electron diffraction of an Fe single crystal showed the presence of the Lorentz effect when the crystal was magnetically saturated. In the absence of a magnetic field, no such effect was observed.—T.G.

Letter: Thermal and magnetic analysis of an Fe–Ni alloy by an electron beam technique S. Yamaguchi (*JISI*, 1960, **196,** Dec., 462) [This issue].

The coercivity of nickel and iron–nickel alloys during plastic deformation E. Kneller and G. Schmelzer (*Z. Metallk.*, 1960, **51,** June, 342–349) The coercivity of single- and polycrystalline Ni and f.c.c. Fe–Ni alloys were measured as a function of plastic deformation. The coercivity of single crystals shows three ranges which correspond to the three parts of the work-hardening curve. The increase in coercive force during deformation is attributed to magneto-elastic interactions between magnetic forces and the eigenstresses of the dislocations created by the deformation (26 refs.)

Principles of measurement and testing possibilities of the Magnatest-Q method in the steelmaking industry F. Michalski and E. Kemenesy (*Materialprüfung*, 1960, **2,** Feb. 20, 56–64) The influence of the geometry, structure, composition, and stresses of the test bars on the readings, and the effects of electrical and other factors are discussed.

Eddy current testing T. J. Baugh (*Wiggin Nickel Alloys*, [1960] (56), 10–16) The theory and practice of the method are given with indications of its usefulness.

A double pulse eddy current testing system C. J. Renken and R. G. Myers (*ANL–5935*, 1959, June, pp.34; from *US Govt. Res. Rep.*, 1959, **32,** Nov.13, 648) No abstract.—S.H.-S.

Influence of carbon content and experimental temperature on the strengthening and specific electrical resistance of ferritic and austenitic steels during cold working E. Schmidtmann, V. Kalla, and H. Brandis (*Arch. Eisenh.*, 1960, **31,** May, 299–308) In ferritic steels a clear relationship was found between increase of strength and the form of precipitation of the C. Precipitation within the grains had the greatest influence in lower C ranges, grain boundary precipitation had little effect, only C contents high enough to form pearlite gave a more pronounced rise in strength. A linear relationship between strength and C content was found in austenitic steels; the results were explained as a variable inhibition of dislocation-movements in residual deformation by slip. The influence of cold work on specified electrical resistance was discussed.

Measurement of sound velocity and attenuation with the impulse ultrasound apparatus and application to cast iron and cast steel W. Grabendorfer (*Berg-hüttenmänn. Monatsh*, 1960, **105,** March–April, 42–46) The principles of ultrasonic testing are explained, for instance the measurement of the velocity of sound, the use of the travel-time meter, the determination of the absorption coefficients, the effect of distance from the probe head, etc.—T.G.

The velocity of sound as a criterion for a number of properties of cast iron R. Ziegler (*Berg-hüttenmänn. Monatsh.*, 1960, **105,** March–April, 46–49) Whereas the velocity of sound in steel is practically constant, it varies considerably in cast iron as a function of graphite content and graphite shape. The potentialities of this phenomenon for an appraisal of cast iron in the foundry are discussed.—T.G.

Study on the possibility of a quantitative determination of the attenuation of the sound intensity by means of the ultrasonic impulse apparatus R. Gerstner (*Berg-hüttenmänn. Monatsh.*, 1960, **105,** March–April, 49–52) The knowledge of the attenuation of the sound intensity allows deductions to be made on properties such as tensile strength, microstructure, inhomogeneities, etc. The author discusses the theory of attenuation measurement and the sources of errors and deviations that may occur in practice.—T.G.

Ultrasonic testing of wire W. Papsdorf (*Stahl Eisen*, 1960, **80,** July 7, 953–954) A new ultrasonic tester for thin wire between 0·1 and 1 mm dia. is briefly reviewed.—T.G.

Defect location in sheet by ultrasonic 'plate waves' H. Wiegand and H. Hentze (*Materialprüfung*, 1960, Feb. 20, 45–50) The principle of this method for testing sheet is described, and its application to the location of various types of defect is illustrated by examples using equipment manufactured by Lehfeld & Co., Heppenheim. The examples include surface defects and slag inclusions.

High resistivity nickel–iron alloys with rectangular hysteresis loops A. Hart (*Brit. J. App. Phys.*, 1960, **11,** Feb., 58–60) Because of its rectangular hysteresis loop magnetically annealed 65/35 Ni–Fe alloy is suitable for many applications. The alloy has a low resistivity however and eddy current effects limit the performance of many devices made from the alloy. An alloy with similar magnetic and a higher resistivity is very desirable. A method of magnetic annealing is described which allows magnetic properties to be induced in alloys containing up to 3%Mo and Ni and iron in the ratio 65–35. Compared with 50/50 grain oriented alloy the 3%Mo alloy has a lower coercivity and a higher resistivity but its saturation flux density is some 20% less.

Depth of indentation on an impacting projectile R. A. Graham (*J. Appl. Phys.*, 1960, **31,** March, 619–620) A letter. Experiments conducted on tests of impact upon a barium titanate ceramic by a 1018 steel projectile fired at high velocity, were designed to study electrical rather than indentation phenomena and the ferroelectric charge release from the barium titanate due to passage of a stress wave produced by impact. Geometry of the arrangement is shown and compared with Backman's method.—S.H.-S.

Ultrasonics for metallurgical testing and measurement J. B. Morgan (*J. Met.*, 1960, **12,** May, 392–397) Several methods are described for the detection of internal and external discontinuities, thickness measurement, and the determination of elastic constants.

Notes on ultrasonic testing S. Cardona (*Met. Ital.*, 1960, **52,** March, 107–119) The article describes methods of ultrasonic testing of axles. Examination of cracks reveal two types of failures, one fast growing and one developing much more slowly with quite different characteristics. A simple method is described of calculating the solid angle of an ultrasonic beam passing through two media of different densities separated by a cylindrical surface. An account is given of ultrasonic acceptance testing of raw and finished materials with special regard to the opacity of ferrous materials. The ultrasonic testing of welds is also referred to.

The most favourable conditions for the non-destructive ultrasonic testing of cast iron test pieces: interpretation and comparison of results obtained J. O. Martinez (*4th Annual Meeting, Inst. del Hierro y del Acero*, 1959, pp.8, ref.A38) [In Spanish] A series of oscillograms are reproduced which were obtained by testing under various conditions, and the results obtained are compared.

Behaviour of ultrasonics in the presence of various types of defects which may be found in welds P. Bastien and M. Evrard (*Soud. Techn. Connexes*, 1959, **13,** Sept.–Oct., 349–357) Results of tests carried out by several laboratories on identical specimens illustrating lack of penetration, blowholes, and slag inclusions were studied in relation to the oscillograms produced.

Radiographic investigation of the destruction of steel specimens by tension-compression alternating stresses. Part II P. Müller and E. Macherauch (*Arch. Eisenhüt.*, 1960, **31,** April, 259–270) The static and dynamic stressing of uniaxially stressed specimens of 25Cr 4Mo steel was examined radiographically in the lattice strain condition controlling the surface-adjacent layers. The investigations were carried out on unnotched specimens and on samples with a shallow cup-shaped notch. The results are discussed (29 refs).

Continuous fluoroscoping spots pipe weld defects United States Steel Corp. (*Steel*, 1960, **146,** April 11, 96) Arrangements for inspecting continuously the whole length of welded seams in 40 ft steel pipes is described. The X-ray head mounted on a 48 ft boom is kept aligned on the inside of the weld as the pipe

moves over it. The shadow image of the weld is thrown on to the fluorescent screen of an intensifier, and is then projected (greatly magnified) on a television monitor screen. An inspector, who controls the movement of the pipe, can thus detect any flaws.—D.L.C.P.

Radiographic weld testing in assembly shops O. Grossi (*Ing. Mecc.*, 1960, **9,** March, 41–47) The applications of industrial radiography in controlling welds carried out in the assembly shop are described. Information is also given regarding various types of radiographical equipment and techniques applied in the assembly shops.

Improvement in the method of X-raying welded joints L. A. Shchekin and A. P. Starostin (*Svarochnoe Proizv.*, 1959, (12), 30–31) To eliminate existing shortcomings in the taking of X-ray pictures of welded tubular joints up to 300 mm dia. and of thick welded-on layers, special arrangements for marking and for the attachment of the film cassette are explained. This arrangement has been in use at the Ordzhinikidze Podol'sk Works with satisfactory results.

Revealing the traces of overheating in the structure of steel by X-rays B. A. Leont'ev (*Izvest. VUZ Chern. Met.*, 1959, (8), 87–89) After overheating to the given temp. above the critical point, the investigation of the martensite transformation in cooling by X-rays reveals the texture characteristics of overheating. This texture persists after repeated heating of the steel within the temp. limits of tempering, and gradually disappears after exceeding the upper critical point. The correlation between the disappearing texture maxima on the X-radiograph and the changing aspect of the fracture becomes clear. The temp. of the total disappearance of the overheated structure corresponds to Chernov's point b. In this way the X-ray method of control of a previously overheated steel is more universally applicable than judging by the appearance of the fracture, because it makes possible the detection of traces of overheating when these no longer appear in the fracture.

X-Ray measurements of elastic stresses in metals E. Schibol'd and Kh. Shtroppe (*Metalloved Term. Obra. Met.*, 1959, (10), 16–19) The chief methods for measuring deformation may be divided into mechanical, optical, and X-ray methods. Mechanical methods are mostly used but the X-ray methods first used in the late 'thirties have gradually spread and now enjoy great popularity. The advantages of these methods are explained.

Study of changes in intensity and width of the X-ray interference lines of Fe–Co alloys under deformation G. M. Vorob'ev (*Izvest. VUZ Chern. Met.*, 1959, (9), 101–110) Under plastic deformation of Fe–Co alloys the distortion of the third order increases throughout the entire range of deformation investigated. With an increase in distortion breaking up of the blocks takes place. The proportion of the substance not taking part in the diffraction of X-rays increases with increasing deformation. The average dimension of the zone of coherent dispersion of X-rays, measured by the width of the lines, reaches its lowest limit with a reduction of about 20%.

Cobalt inspection unit detects flaws in vital castings Southern Pacific Foundries (*Iron Age*, 1960, **185,** March 17, 102–103) A flaw-detecting radiograph unit for testing castings such as atomic power plant valves is described. The 1000 Curie radioactive source is ^{60}Co, and thicknesses up to 10 in. can be tested with a sensitivity of 1%.—D.L.C.P.

The inspection and control of welds by gamma radiography J. Metayer (*Mét. Const. Méc.*, 1960, April, 261–269) The use of γ-radiography for inspection of weld beads, with choice of sources, operative standards, and apparatus are described. Various characteristic defects of welding beads are shown.

Alpha excitation functions of iron-54 S. Tanaka, M. Furukawa, M. Yagi, S. Iwata, and H. Amano (*J. Phys. Soc. Japan*, 1959, **14,** Sept., 1251) Excitation functions of the reactions ^{54}Fe (α, n) ^{57}Ni, ^{54}Fe (α, p) ^{57}Co, ^{54}Fe (α, $2n$) ^{56}Ni, and ^{54}Fe (α, pn) ^{56}Co were measured by the activation method. The results are plotted on graphs. σ (α, p) was generally a few times larger than σ (α, n). σ (α, pn) was larger than σ (α, $2n$) by a factor of 100. Owing to the poor knowledge of the decay scheme on ^{56}Ni the latter result is somewhat ambiguous. The results are analysed on the basis of the statistical theory of nuclear reaction.

Effect of nuclear radiation on engineering materials A. H. Cottrell (*Chartered Mech. Eng.*, 1960, **7,** March, 105–118) In the forty-sixth Thomas Hawksley lecture the pattern of hazards in various reactor projects, the handling of their materials with special reference to their resistance to radiation, creep, and corrosive attack are followed by a review of radiation damage, knock-on damage, knock-on damage in graphite, radiation hardening in metals and radiation embrittlement of steel. Reactor pressure vessels, and their safety against brittle fracture, the dimensional instability of U, radiation creep, and the bowing of fuel elements, swelling of U by fission gases are covered in a review of gas-cooled, graphite-moderated reactors. The value of modern theory for attacking the problems encountered is noted in view of the extremely expensive and time-consuming nature of experimentation on reactor materials.

The special behaviour of nitrided 1Kh18N9T steel during long time exposure at high temperature A. V. Kostenko, E. V. Lopukhina T. M. Pogrebetskaya, and A. A. Yurgenson (*Fiz. Met. Metalloved.*, 1960, (6), 868–877) The increase in the depth of the nitrided layer and in its weight with the time of nitriding at 680° proceeds according to a parabolic law. The saturation of this steel by nitrogen shows a phase transformation in the surface layer: a partial decay of the austenite with segregation of the magnetic α-phase. Cr binds the nitrogen in the form of nitrides of the composition CrN. A prolonged exposure at 680° results in the appearance of a two-layer scale the external surface one of which is Fe_2O_3 and the inner layer a complex oxide $(CrFe)_2O_3$. The iron nitrides dissociate.

The distribution of the elements in complex-alloys on an iron base M. A. Krishtal and E. P. Rikman (*Fiz. Met. Metalloved.*, 1960, (5), 790–792) In a complex alloy a high temp. anneal does not increase the uniformity of its chemical composition. The experimental data here reported show that in the case of alloy elements of the Si and Ti type when present together, a high temp. anneal results in an opposite effect, i.e. it reduces the uniformity of their distribution as a result of which the free energy of the system diminishes.

The stability of the conditions arising with the ordering of the work-hardened Fe_3Al alloys Ya. P. Selisskii (*Fiz. Met. Metalloved.*, 1960, (3), 472–472) The different heating curves plotted from dilatometer readings for Fe–Al alloys of different initial structural conditions, all heated at the rate of 5°/min are considered. The conclusions are that the structural condition appearing as a result of the ordering of the deformed lattice is more stable in the subsequent heating than the structural condition which occurs as a result of the ordering of an original structure which was first quenched.

Impairment of the properties of tungsten steel F 233 magnets J. Terraza Martorell and J. M. Bermudez de Castro y Mosquera (*Hierro y Acero*, 1960, **13,** Jan.–March, 320–377) The different methods of measurement of the magnetic properties of ferromagnetic materials, for determining magnetization curves and cycles of hysteresis are described, in the graphs covering magnetic variations due to times and temp. of annealing and times of sintering.—S.H.-S.

Investigating texture and the anisotropy of magnetostriction in Fe–Al and Fe–Cr alloys M. M. Borodkina, Z. N. Bulycheva, and Ya. P. Selisskii (*Fiz. Met. Metalloved.*, 1960, (3), 390–399) The deformation texture of these alloys is characterized by the following three main magnetic directions, (100) [011]; (111) [1$\bar{1}$2], and (112) [1$\bar{1}$0]. There exists a measurable relation between deformation texture and recrystallization: The intensification in the (111) [1$\bar{1}$2] orientation results, after tempering, in the development of the (110) [001] and (100) [001] orientations, which may also be achieved in rolling with small total rates of reduction (50–60% and a few intermediate anneals. Rolling with a large reduction (80–90%) and one anneal results in an intensification of the (112) [1$\bar{1}$0] orientation, and after a final tempering, to complex orientations not ensuring the needed anisotropy of magnetostriction in the sheet.

The temperature magnetic hysteresis of silicon-iron L. V. Kirenskii, D. A. Laptei, A. I. Drokin, and R. P. Smolin (*Fiz. Met. Metalloved.*, 1960, (3), 337–344) Ferromagnetic bodies placed in a constant magnetic field change their magnetizability with changes in temp. Up to the present, the relevant investigations were carried out on polycrystalline specimens. In this paper experiments with the thermal magnetic hysteresis (TMH) on monocrystals are described. The iron contained 3·8%Si. The specimens were cut by etching along the principal and intermediate crystallographic planes and were annealed *in vacuo* at 1100° for 4 h and then cooled slowly. Results of measurements of the TMH in the directions [100] [110] and [111] are shown on graphs.

Special features of the relation between the energy of the magnetic anisotropy of the Fe–Al alloys and temperature I. M. Puzei (*Fiz. Met. Metalloved.*, 1960, (2), 279–282) The atomic magnetic structure of the Fe–Al alloys in the domain of the Fe_3Al phase is similar to that of alloys with ferromagnetic elements with different values of their magnetic moments. (Fe–Ni; Ni–Fe–Mo; Ni–Co; Fe–Co). In the Fe–Al alloys some special features are observed viz.: the dependence of the anisotropy constants on temp., the presence of a maximum, the existence of an inverse ratio and of a change in sign, i.e. peculiarities of ferromagnetic alloys, the components of which have different magnetic moments.

Anomalies of the magnetic properties of the Fe–Al alloys at high temperatures Sh. I. Zusman (*Fiz. Met. Metalloved.*, 1960, (1), 41–47) The Fe–Al alloys containing 8–12% of Al by weight have, at high temp., properties typical of the perminvar alloys. At room temp. the traces of 'perminvariability' appear in the form of the increased sensitivity of these alloys to the action of strong magnetic fields and of abnormally low values for residual induction. A regular relation between the perminvar effect and that of the thermo-magnetic action has been observed (in a magnetic field increased remanence occurs and the hysteresis loop assumes its normal shape.

Investigations of the influence of nonmetallic inclusions on the demagnetization losses of iron-silicon transformer sheet D. Seeger (*VDIZ*, 1960, **102,** May, 529–530) A brief abstract of a thesis to appear in *Arch. Eisenhütt.*. The effects on magnetic properties of the presence of nitride inclusions are discussed.

The electrical resistance of the Fe_3Al alloy in cold deformation and in the subsequent thermal treatment Ya. P. Selisskii (*Fiz. Met. Metalloved.*, 1960, (4), 633–635) The electrical resistance was measured on a series of cold-deformed specimens, later annealed at 850° for 20 min. and cooled at different rates. It has been noticed that the drop in the electrical resistance with an increasing degree of deformation is accompanied by texture changes. An analysis of texture has shown that it consists, in addition to the (001) [110] orientation, of at least three more complex orientations which persist in the recrystallization texture.

The effect of copper on transformer steel N. F. Dubrov, I. A. Gorlach, and M. V. Lyasko (*Stal'*, 1960, (7), 645–646) Steel with 4·6%Si is shown to be adversely affected by Cu. For steels standardized by specific losses an upper limit of 0·4%Cu and for those standardized by permeability in weak magnetic fields a limit of 0·2% is suggested. Steels for service in very weak fields of ~0·008 amp. turns/cm or less should be free from Cu as far as practicable.

X-Ray analysis of iron–vanadium alloys after plastic deformation and tempering L. I. Mirkin (*Izvest. VUZ Chern. Met.*, 1959, (11), 93–96) In the Fe + 2%V alloy no measurable distortions of the IInd order occur in cold plastic deformation or in filing. The blocks in the rolled metal are of the order of 5×10^{-6} cm, i.e. smaller than in the iron subjected to the same treatment. During the tempering of deformed alloys the blocks grow much more slowly than in iron.

X-Ray analysis of the changes in the structure and mutual arrangement of individual grains in specimens of low alloy iron during deformation by simple tension V. N. Sheherbakov L. N. Nagovitsyna, and I. S. Osipov (*Fiz. Met. Metalloved.*, 1960, (4), 510–514) The method consists of taking X-ray photographs in a flat cassette placed at right angles to the primary X-ray beam of the interference lines at a small angle. The specimens were flat parallel platelets 0·05 × (8–9) × (22–24) mm and made by rolling a previously annealed sheet of 0·5 mm thickness. The prepared specimens were subjected to a recrystallization anneal at different temp. and with different times of ageing. The interference lines so taken gave 300–400 spots which were then examined under different degrees of tensile deformation from 0·05% to 5·4% and the interpretation of the interference lines with every degree of deformation is discussed.

The application of X-ray scanning microanalysis to some metallurgical problems D. A. Melford and P. Duncumb (*Metallurgia*, 1960, **61,** May 205–212) The scanning technique in X-ray microanalysis is described; its particular value lies in the detection of the distribution of a constituent or impurity within a metal. A number of applications are quoted, e.g. the effect of hot-shortness of surface segregation in mild steel; the segregations of lead in free-cutting steels, etc.—T.G.

Absorption of the beta-radiation of ^{60}Co in refractory materials D. M. Shakhtin and V. D. Kovalev (*Zavods. Lab.*,1960, (2), 173–175) The use of β-radiation for solving various scientific problems needs a precise knowledge of the absorption coefficient of the materials, among which are refractory materials. Theoretical and practical considerations of this problem are set out and the findings for the different refractory materials investigated are tabulated.

Ultrasonic attenuation in SAE 3140 and 4150 steel E. P. Papadakis (*AD* 213478; *PB* 142424, 1959, April, pp.93; from *US Govt. Res. Rep.*, 1959, **32,** Oct. 12, 498) Attenuation of longitudinal ultrasonic waves is studied by pulse technique in blocks of SAE 3140 and 4150 steel to determine loss mechanism and find methods for precision testing microstructure of materials. Scattering by the grains in polycrystalline steel is responsible for attenuation in tempered steel. Critical quantities are grain dia. and root mean square fractional variation of elastic modulus of a single grain. Diffraction corrections and other items relevant to ultrasonic attenuation measurements are mentioned.—S.H.-S.

Attenuation of ultrasound, structure and degree of homogeneity of cast iron and cast steel R. Mitsche (*Berg-hüttenmänn. Monatsh.*, 1960, **105,** March–April, 52–60) The author reviews present knowledge of the relation between ultrasound attenuation and microstructure and reports on his own investigations to elucidate this relation, in particular the question whether 'ultrasonically homogeneous' zones exist in castings. He concludes that at present the application of the integral measurement of the attenuation of ultrasound is neither feasible for an appraisal of the structure nor for the detection of certain defects such as microcracks, fine pores, sponginess, etc.—T.G.

Ultrasound: a tool for metallurgical research H. Stäger and R. Meister (*Berg-hüttenmänn. Monatsh.*, 1960, **105,** March–April, 60–74) The velocity of ultrasound which can be measured easily and accurately has been used for the determination of the elastic constants of metals including pig iron, cast iron, and steels; the elastic constants are: elastic modulus, shear modulus, Poisson's ratio, and compressibility. Details of the determinations and the effect of microstructure on the various elastic constants are described.—T.G.

Ultrasound: one of the many methods for testing castings R. Schinn (*Berg-hüttenmänn. Monatsh.*, 1960, **105,** March–April, 74–76) The usefulness and wide applications of ultrasonic testing of large steel castings and forgings are briefly described.—T.G.

Quality control of iron castings by ultrasound G. Bierwirth (*Berg.-huttenmänn. Monatsh.*, 1960, **105,** March–April, 76–83) The author reports experience gained during the last two years in a car factory on the quality control of mass-produced iron castings. In spite of the still existing deficiencies in the ultrasonic method of testing—which the author believes will be reduced or even eliminated in the future—the method has its merits as it is non-destructive and therefore applicable to very large numbers—T.G.

The practice of ultrasonic testing of large steel castings W. Rauterkus (*Berg-hüttenmänn. Monatsh.*, 1960, **105,** March–April, 83–88) The author describes the practice of ultrasonic testing of large steel castings and discusses the difficulties encountered and points out the differences in the appraisal of a forging and a casting. The internal structure of a casting may lead to a wrong judgment and it requires long experience and in many cases also destructive tests before a final appraisal can be made.

Relation between the results of ultrasonic testing and the strength properties in plain carbon steel castings E. Krainer (*Berg-hüttenmänn. Monatsh.*, 1960, **105,** March–April, 89–90) The reflectogram of defect-free samples is never a straight line but shows a large number of little peaks. Destructive tests showed that these peaks are inhomogeneities in the material. If these little peaks change quickly when moving the probe head a little, it can be assumed that the inhomogeneities are harmless, although elongation of the test pieces may be impaired. If, on the other hand, a strong damping effect is observed when moving the probe head, a serious defect must be expected.—T.G.

Studies on defects in models R. Gerstner (*Berg-hüttenmänn. Monatsh.*, 1960, **105,** March–April, 88–89) Tests on defects in models show that the amplitude of the back reflection of ultrasonic vibrations is not directly proportional to frequency, depth of the defect, and distance of the defect from the probe head, but that unpredictable deviations occur. The author attributes these irregularities to interference phenomena near the probe head.—T.G.

Application of ultrasonic testing to cast iron rolls R. Gerstner (*Berg-hüttenmänn. Monatsh.*, 1960, **105,** March–April, 91–92) The main properties of a cast iron roll that should be determined with ultrasound are: chill depth of chill cast rolls, proportion of spheroidal graphite in spheroidal graphite cast iron rolls, elastic modulus, and the presence of defects. The author describes the procedure for the determination of each item.—T.G.

Magnetic contribution to the ultrasonic attenuation in annealed and deformed steel (SAE 120) W. J. Bratina, U. M. Martius, and D. Mills (*J. Appl. Phys.*, 1960, **31,** Supplement, May, 241s–242s) The absorption of ultrasound of ~3 Mc/sec frequency was investigated in low-carbon steel as a function of elastic strain applied in the presence of constant magnetic fields. The major part of the observed attenuation changes appears to be due to variation in the amplitude of the domain wall vibration while the domain configuration changes appear to have relatively little effect. The maximum observed in the attenuation strain curve for plastically deformed materials is attributed to the presence of internal stresses.

The dependence of X-ray diffraction pattern upon the process of sintering in Fe Al Ni magnet alloy K. Shida (*Nippon Kinzoku*, 1959, **23,** April, 203–205) For the $FeAl_2$ Ni–Fe system, the changes of X-ray pattern at 700°C corresponding with various stages of diffusion are described. At 1250°C a new (α)-phase appears in the pattern. Particle size has an intense effect on homogenization rate. Excellent magnetic properties can be obtained with the composition Fe63, Ni25, Al12%.—K.E.J.

Recommended practice for radiographic inspection of circumferential fusion welded butt joints in steel pipes up to 50 mm (2 inch) wall thickness IIw, Commission V (*Soudage*, 1960, **14,** March–April, 119–124) Recommendations are made for the inspection of welded butt joints on tubes, and other cylindrical bodies, e.g. pipes, penstocks, boiler tanks, pressure vessels, etc. They should not be considered as standards for the approval of joints, but only from the viewpoint of radiography.—S.H.-S.

Radiographic determination of a phase with a preferred orientation P. Bastien and R. Margerand (*Compt. Rend.*, 1960, **250,** Feb. 29, 1656–1658) An accurate method of determining a phase in a two-phase alloy is described, with particular reference to the cold-worked α-phase of an unstable austenitic steel.

The principles of gamma-ray attenuation E. Pohl (*Technik*, 1960, **15,** June, 413–418) Using the principles of γ-ray attenuation and absorption the author explains the requirements on materials used for γ-ray protection.—T.G.

Width and intensity of the Mössbauer line in iron-57 M. Cordey-Hayes, N. A. Dyson, and P. B. Moon (*Proc. Phys. Soc.*, 1960, **75,** May, 810–811) A letter.

The applications of radioisotopes in metallurgy A. Kohn (*Bull. Cercle Etudes Mét.*, 1960, **8,** March, 1–33) A survey of the properties of the principal isotopes used, and a detailed account of several applications to metallurgical research in France (33 refs).

Tracing of hidden defects with isotopes P. Réti (*Koh. Lapok*, 1959, **14,** June, 267–273) The author describes the use of radioisotopes such as ^{60}Co, ^{192}Ir, ^{137}Cs, and ^{182}Ta in the inspection of the products of a Hungarian iron and steel foundry and in the examination of steel welds.—P.K.

Effects of irradiation on stainless-steel clad UO_2 pellets in helium or carbon dioxide G. E. Lamale (*BMI*–1335, 1959, April, pp.18; from *US Govt. Res. Rep.*, 1959, **32,** Sept. 11, 404) (No abstract).

Density of iron, nickel and cobalt in the liquid state L.-D. Lucas (*Compt. Rend.*, 1960, **250,** March 7, 1850–1852) The variation of specific volume is investigated as a function of temp. and the results obtained compared with those of other workers.

High-alloy steels for use as a thermal conductivity standard R. W. Powell and R. P. Tye (*Brit. J. Appl. Phys.*, 1960, **11,** May, 195–198) A method of measurement of conductivity in Macloy G steel at 0–180°C is described and along with measurements on Armco at 300–800°C give values within ±2% over the whole range. These and Era ATV steel are suggested as standards.

Introduction to high temperature metals J. C. Merriam (*Mat. Design. Eng.*, 1960, **51,** June, 143–158) M/DE Manual No.172. Properties required, uses, available materials (including iron-base alloys) their performance, stress-rupture properties, and heat and oxidation resistances are shown in curves and tables.

Determination of tensile, compressive, bearing and shear properties of sheet steels at elevated temperatures J. R. Kattus, J. B. Preston, and H. L. Lessley (*WADC Technical Report* 58–365; *ASTIA Document No.*206075; *PB* 151592, 1958, Nov., pp.274) The effects were examined of exposure times of up to 1000 h on the elevated-temp. tensile, compressive, bearing, and shear properties of six aircraft structural sheet steels. Test temp. ranged from room temp. to 1200°F.

Specific heat of chromium–iron alloys at room temperature K. Schröder (*Phys. Rev.*, 1960, **117,** March 15, 1500–1501).

Hot wire method for rapid determination of thermal conductivity W. E. Haupin (*Am. Ceram. Soc. Bull.*, 1960, **39,** March, 139–141) Thermal conductivity is calculated from the rate of temp. rise of a butt-welded thermocouple inserted into the specimen and heated by ac. An electrical network is described which allows the reading of a fraction of a millivolt thermal emf in the presence of several volts of alternating current, being rapid and simple to run and without complicated equipment.—S.H.-S.

Effect of elevated temperatures on high-tensile steel wires for pre-stressed concrete M. F. Day, E. A. Jenkinson, and A. I. Smith (*Proc. Inst. Civil Eng.*, 1960, **16,** May, 55–70) A study of conditions to be expected in case of fire was made. Data on creep and stress relaxation at room temp. and metallographical studies over a range of temp. are included.

Low temperature properties of engineering materials R. F. Barron (*Machine Design*, 1960, **32,** March 17, 189–195) Data for stainless steels and non-ferrous alloys are shown in curves.

The behaviour of carbon and nickel steels at low temperatures: their use in the construction

of welded pressure containers C. Babocci (*Calore*, 1960, **31,** April, 213–220) The results are given of a series of tests carried out at various temp. on Al-killed steel quality Aq42 produced under the supervision of the metallurgical department of a large steelworks.

The use of steels between room temperature and −70°C A. Keller and W. A. Stauffer (*Schweiz. Arch.*, 1960, **26,** March, 89–99) The use of steels in refrigeration is greatly impaired by the reduction in impact toughness with falling temp. If the steels are produced by special methods even plain or only low-alloy steels may be employed down to temp. of −70°C. These problems are reviewed in detail, included in this review is the welding of the steels and the acceptance testing.—T.G.

The properties of materials in the low-temperature region of liquid gases L. Piatti (*Schweiz. Arch.*, 1960, **26,** March, 100–109) The author reviews the properties of many materials including steels at the temp. of liquid gases such as O_2 and H_2. He points out the difference in the behaviour of unalloyed and austenitic steels in this temp. range. The brittle fracture phenomenon is briefly discussed and explained in terms of dislocation theory (24 refs).—T.G.

On the function of nitrogen as an alloying element in heat-resisting materials. V. Influence of melting atmosphere on heat-resisting property of 316 L type steels M. Okamoto, R. Tanaka, and A. Sato (*Tetsu to Hagane*, 1959, **45,** Dec., 1351–1357) Compared with air- and vacuum-melted steels, nitrogen-melted steel had better hardness and strength at room temp. in states preceded by solution-quenching. It had significant resistance to recrystallization-softening and good high-temp. bending creep and tensile creep-rupture properties. Thermite-process Cr induced better bending creep properties than electrolytic Cr (11 refs).—K.E.J.

Effect of phosphorus and nitrogen on the hardness of rimming low-carbon steel after various pretreatments A. Drevermann (*Stahl Eisen*, 1960, **80,** June 9, 801–809) OH converter steels refined with O_2-enriched or O_2+CO_2-enriched air, basic Bessemer steels, and Armco iron were used in this investigation on the effect of P and N on the hardness of steels after various heat-treatments and working operations. The results show that hardness in the normalized state increased proportionally to P and N contents, the N having an effect on hardness about 10 times that of the P. The results are discussed in terms of recovery and recrystallization theory. It was also found that the N shows a very pronounced tendency to segregation.—T.G.

Silicon in metallurgy W. E. Remmers (*Ing. e. Indust.*, 1960, **27,** April, 101–105) The effects of silicon in steel, with and without other alloying additions, and in cast iron are discussed.

The Wright Air Development Centre elevated temperature test facility R. B. Baird (*Proc. Soc. Exper. Stress. Anal.*, 1959, **17,** (1), 37–49) A brief description is given of the equipment in the WADC Pilot Plant and its capabilities as regards elevated temp. structural test facility. Various heating methods are discussed and the flexibility of radiant heating is illustrated by a description of a recent test programme from the results of the Pilot Plant programme the design requirements for its full-scale expansion are presented and progress made is described.

Unsolved problems of elevated temperature instrumentation R. L. Cavanagh (*Proc. Soc. Exper. Stress. Anal.*, 1959, **17,** (1), 51–55) An attempt is made to point out instrumentation problems associated with structural testing of aircraft at elevated temp. It is felt that predominant problems occur when attempting to measure strains due to transient heating and that the strain transducers available at present are inadequate for this purpose at temp. in excess of 350°F.

A versatile high temperature testing machine for creep, stress relaxation and static tension tests W. N. Findley and W. J. Worley (*Proc. Soc. Exper. Stress Anal.*, 1959, **17,** (1), 15–22) A machine is described on which the following tests can be performed: creep both for small and large strains, stress relaxation, and short-time tension tests. New features include a device for accurate positioning of the specimen within the furnace, an extensometer which will compensate for dimensional instability of the test material, grips with spherical seats at the ends of the specimen and means for minimizing the effects of vibration and shock.

Evaluation of high temperature strain gauges G. F. Brosius and D. Hartley (*Proc. Soc. Exper. Stress Anal.*, 1959, **17,** (1), 67–84) Both Nichrome 'V' foil and weldable gauges evaluated in a cantilever beam were set up in the laboratory. The effect of temp. up to 1100°F on gauge characteristics were determined. Zero shift versus temp. curve are given for temp.-compensated gauges measuring bending strain. Variation in gauge relative to sensitivity with temp. is measured. Nichron 'V' foil gauges were also evaluated in a field installation. Zero shift with temp. curves along with other valuable data were recorded to compare accuracy of laboratory and field work.

Materials below −100°F O. A. Hansen (*Mech. Eng.*, 1960, **82,** April, 60–62) A brief review of the properties of irons and steels and non-ferrous metals classified as face-centred and body-centred lattice materials.

Steels for low temperatures H. Lejay (*Chim. Ind.*, 1960, **83,** June, 868–874) Tests used for such steels at high and low temp. are reviewed and the composition of steels and the effects of the various alloying elements are discussed in general terms, especially for the range −50 to −200°C, and also the effects of heat treatments and welding.

The strength properties of rolled and cast austenitic 18:8 chromium nickel steels at +20 and −180°C: Part II H. Schumann (*Technik*, 1960, **15,** June, 401–406) A review mainly of English and American publications on the use of austenitic steels for extreme low temp. (36 refs).—T.G.

Metal diffusion R. L. Samuel (*Auto Eng.*, 1960, **50,** (3), March, 116) Comments of a critical nature on a previous article describing the 'Dicron' process are given, dealing mainly with fundamental aspects of diffusion. Author's reply is given, which includes a number of references.—A.H.M.

Diffusion in metals P. G. Shewman and F. R. Winslow (*Ind. Eng. Chem.*, 1960, **52,** April, 343–346) A review for the year (105 refs).

Study by diffraction and electron microscopy of the diffusion of carbon in iron and aluminium J. J. Trillat, L. Tertian, and M. Bonnet-Gros (*Rev. Mét. Mem. Sci.*, 1960, **57,** Feb., 81–87) By studying as a function of time and temp. the transformation of a composite film, made by evaporating Fe on to a C membrane under high vacuum in an electron microscope or electron-diffraction camera, and heating to 1000°C, the diffusion of C in Fe in the absence of oxidation was followed. Conditions of formation, stability, and decomposition of Fe_2C and Fe_3C are shown. Similar experiments were carried out with Fe on a polythene membrane, and the diffusion of C in Al was also studied (12 refs).

Determination of diffusion coefficients in solids by the residual activity method R. H. Condit (*Metallurgy Rept. No.19, AFOSR TN-59-150; AV-210985; PB 140812*; 1959, Feb., pp.19; from *US Govt. Res. Rep.*, 1959, **32,** Sept. 11, 370) The correct procedure for relating the count of activity after each count to the actual concentration of radioactive tracer is presented, computed correction factors are given graphically, and their use illustrated by an example.

Hydrogen in steel M. G. Neu (*Foseco Found. Devel.*, 1960, April, 2–14) Methods of reducing H_2 content and the development of a solid degassing agent in block form are described, it evolves $CO+CO_2$ and numerous trials are reported.

Contribution to the knowledge of the behaviour of hydrogen in steels W. Hofmann and G. Vibrans (*Rev. Mét. Mem. Sci.*, 1960, **57,** Feb., 88–90) The solubility of H_2 in a killed steel containing 0·22%C was determined after charging with H_2 under pressure at 200–700°C. The values at 200 and 300°C fall above the curve (extrapolated) previously published, the difference being attributed to porosity. The presence of H_2 does not lower the fatigue strength appreciably, but an irreversible fall occurs after cold working, or during the cooling of a H_2-rich weld.

'Hydrogen and fish-eyes in steel'. (Review of book by D. Ya. Povolotskii and A. N. Morozov V. I. Yavoiskii (*Stal'*, 1960, (6), 505–506).

Mn–V steel for large forgings R. Šejnoha (*Met. Treatment*, 1960, **27,** Feb., 53–59) Tests have been carried out on a typical steel used for large forgings (0·23%C, 1·10%Mn, 0·20%V) to study the effect of V content on mechanical properties. The work was aimed at finding out the causes of cracking in the segregation areas of forgings and the author concludes that for large forgings, where the degree of forging is generally small, V content should be reduced to a minimum or it should be replaced by other elements.—A.H.M.

The selection of alloy steels (*Tecn. Indust.*, 1960, **38,** Feb., 206–210) Compositions, characteristics, and uses of alloy steels are discussed.

Special carbon steels R. W. Vanderbeck (*Chem. Eng.*, 1960, **67,** May 30, 103–106) This article is the first of a series dealing with low temp. construction materials. Low temp. containment must keep up with process technology particularly as the techniques go further down the temp. scale. A number of alloys are available with excellent subzero properties but each has certain disadvantages. This article describes the benefits and shortcomings.

Research into tool steels (*Mech. World*, 1960, **140,** May, 189–190) A summary of some work on carbides, grain-growth, 'fish-scale' fractures, the prediction of hardenability, red hardness, heat-treatment of 1%C steel, residual stress after abrasive tumbling and discontinuous grain growth.

Hot work tool steels W. Sorby (*Alloy Met. Rev.*, 1960, **9,** March, 2–8) A discussion of the properties and uses of a range of steels with special reference to their use for tools and dies. Alloying elements are briefly reviewed and effects of heat-treatment on hardness, tensile properties, etc. are discussed. A list of steels is included. (June, 2–6) A review of steels recently introduced giving their properties and uses, particularly for extrusion and pressure die-casting dies.

Hot work steels for aircraft structures E. A. Loria (*Alloy Met., Rev.* 1960, **9,** June, 7–8) Based upon articles in *Materials and Methods*.

Stainless steels E. Gregory (*Eng. Mat. Des.*, 1960, **3,** July, 435) Data sheet No.40, giving a table of physical and mechanical properties and heat-treatments.

Heat-resisting stainless steels (*Eng. Mat. Design*, 1960, **3,** March, 181) Data for eight heat-resisting stainless steels are given. These include hot working procedure, physical properties, welding properties, and safe working loads for various temp. conditions.—A.T.

Stronger cast stainless keeps promises E. A. Schoefer (*Chem. Eng.*, 1960, **67,** March 7, 164, 166, 168) An account of the properties of CD-4MCu alloy which is double the strength of 18-8 and has excellent corrosion resistance.

Stainless steels for aircraft and missiles A. M. Hall (*Battelle Techn. Rev.*, 1960, **9,** April, 9–14) Properties, especially creep strengths, of martensitic, semiaustenitic ph, and cold-rolled austenitic stainless steels are reviewed.

Ultra-high-tensile steels L. L. Arundel and R. Kitchingham (*Aircraft Prodn.*, 1960, **22,** May, 176–186) A study on the use of CO_2 as a coolant and various cutting fluids in the machining of high-tensile steel and the development of special cutters with a view to determining the machinability of H50 Vacumelt with a tensile strength of 120 t/in^2.

15 Kh2GN2TRA boron steel to replace 12 KhN3A, 12Kh2N4A and 18 KhNVA steels M. F. Alekseenko and G. N. Orekhov (*Stal'*, 1960, (6), 548–551) The steel suggested can be case-hardened over a wide temp. range without grain growth and is equal to the other steels in properties and economizes Ni.

METALLOGRAPHY

The electron-emission microscope as a tool in metallurgy H. Düker (*Z. Metallk.*, 1960, **51,** June, 314–321) An electron-emission microscope is described in which the object is bombarded with ions which cause it to emit electrons. The principle and design of the microscope are described and its applications to metallurgy outlined. The resolution attained

so far is about 500 Å, the temp. of the object may vary between 20 and 1100°C. The effect of the ion bombardment on the objects is discussed and a number of micrographs are reproduced. The magnifications shown range from 1000 to 1400×, one micrograph at 1900×, and one at 4200× are also included. Contrast and sharpness of the pictures are excellent, that at 4200× is a little blurred (19 refs).—T.G.

The physical foundations of image formation in the electron microscope E. B. Bas (*Schweiz. Arch.*, 1960, **26,** April, 138–156) The author deals with the principle of electron lenses, the electron gun, the design of the electron microscope, the formation of contrast in the transmission electron microscope, and the resolving power, and, finally, the moiré technique. In the chapter 'microscopy of surfaces', the replica method is mentioned, reflexion microscopy, emission microscopy, and the scanning electron microscope are described (12 refs).—T.G.

Preparation techniques in electron microscopy K. Mühlethaler (*Schweiz. Arch.*, 1960, **26,** April, 157–162) Replica techniques, shadow casting, and the use of the ultramicrotome are considered (13 refs).—T.G.

Application of electron microscopy A. Saulnier and P. Mirand (*Met. Treatment*, 1960, **27,** March, 91–100, 102) The authors point out the advantages of using thin metal films directly under the electron microscope, thus the micro-diffraction diagram corresponds with the micrographical image. The authors' method of producing such thin foils in metals and alloys is described. Examples of the application of techniques are given.—A.H.M.

Carbon arc image surface and microscope for studies at high temperatures H. W. Newkirk and B. B. Brenden (*HW* 59323, 1959, May, pp.30; from *US Govt. Res. Rep.*, 1959, **32,** Nov.13, 649) (No abstract).

Studies of the structure of iron and steel with the electron microscope A. Schrader (*Schweiz. Arch.*, 1960, **26,** April, 163–170) The use of extraction replicas for the electron-microscopical study of segregations which have formed during prolonged straining at elevated temp. in austenitic and ferritic steels is described and a number of micrographs is reproduced (12 refs).—T.G.

Etch pits in deformed alpha-iron G. Bassi (*Z. Metallk.*, 1960, **51,** June, 357–359) Samples of a Swedish mild steel were plastically deformed at room and liquid-N_2 temp. and the etch pits observed after electropolishing. The different appearance of the etch pits and etch bands are explained.—T.G.

The electrolytic etching of multiphase iron–chromium nickel alloys in sodium hydroxide solution W. Schaarwächter, H. Lüdering, and F. K. Naumann (*Arch. Eisenh.*, 1960, **31,** June, 385–391) With the object of obtaining the best results in etching Fe–Cr–Ni alloys, with particular emphasis on the recognition of σ-phase, experiments were made using NaOH. The best results were obtained by electrolytic etching with 10 N NaOH, using a potentiostat. Details of the experiments are given and the results discussed (13 refs).

The theories and metallurgical uses of thermal etching A. Morgan (*J. Bhm. Met. Soc.*, 1960, **40,** June, 31–41) A survey of the phenomena and a discussion of the mechanism of groove formation, mainly with reference to ferrous alloys.

Novel, nondestructive electrolytic polishing and replica techniques for metal surfaces P. A. Jacquet (*Metalloberfläche*, 1960, **14,** June, 161–170) The Ellopol technique for local electropolishing of metal surfaces is described. Replicas are taken from the specimens and used for microscopical studies. A number of micrographs is reproduced (30 refs).—T.G.

Oxide inclusions in iron chromium oxygen melts W. Koch, J. Bruch, and H. Rohde (*Arch. Eisenh.*, 1960, **31,** May, 279–286) It is shown that the structure of Cr-containing inclusions in Fe–Cr alloys with >3%Cr is related to cooling conditions, heat treatment, and Cr content of the melt. The inclusions were isolated electrolytically followed by vacuum chlorine treatment or magnetic separation, and the structures were examined radiographically and by chemical analysis. Full details of the results are given. Synthetic alloys were used, containing only traces of C, Mn, and Si (11 refs).

Relationships between steel composition and nonmetallic inclusions in aluminium-killed steels F. Kubik (*Radex Rundsch.*, 1960, April, 86–99) Relations between steel composition and the composition of the non-metallic inclusions are analysed statistically on low-C steels. Al first strongly reduces SiO_2, then oxides of Mn and Fe, and at the same time combines with N_2 (28 refs).

Influence of the pH value of the electrolyte solution on the amount and composition of the isolated oxide inclusions of fully killed basic Bessemer steels E. Piper, H. Hagedorn, and M. Fröhlich (*Arch. Eisenh.*, 1960, **31,** June, 355–358) A basic Bessemer steel fully killed with Ca–Si was electrolysed in citrate-bromide solution, the pH value of which was varied between 6·8 and 1·0. No variation in amount or composition of the oxide residues was found.

Thermo-dynamics of the crystallisation of metals A. Horváth (*Koh. Lapok.*, 1959, **14,** Oct., 463–466) The thermodynamic and kinetic conditions of the crystallization of metals are discussed.—P.K.

Recrystallisation of austenite in a structural steel submitted to hot plastic deformation S. Gorczyca (*Rev. Mét. Mem. Sci.*, 1960, **57,** Feb., 153–158) About 30% deformation was obtained by forging a steel containing 0·36%C, 0·72%Mn, 0·29%Si, 1·43%Cr, 1·46%Ni, and 0·23%Mo at temp. from 850–1050°C. The recrystallization process was observed after quenching, and the rate of growth of the new austenite grains was found to be $V = Ke^{-Q/RT}$ where $K = 8 \cdot 9 \cdot 10^8$ mm/s, and Q = 61 000 cal/g-atom (15 refs).

Investigations on the recrystallisation of a ferritic steel with 27%Cr with special reference to the duration of annealing H. Borchers, K. Bungardt, and D. Pusch (*Arch. Eisenhütt.*, 1960, **31,** March, 177–182) The importance of taking into account the effects of annealing time in studying recrystallization is discussed, and the results of hardness measurements and microscopical examination of a cold rolled 27%Cr steel given a recrystallizing anneal are described. The results discussed are: hardness after a 24-h heat treatment at 200–500°C and at 500–1200°C for up to 2 h as a function of degree of working (up to 70%); and grain size after heat treating at 600 to 1200°C as a function of degree of working and duration of annealing (35 refs).

Deformation and recrystallisation in (110) [001] single crystals of iron–silicon alloy Wang Wien-min, Chou Pang-hsin, and Chen Neng-kuan (*Acta Phys. Sin.*, 1960, **16,** May, 263–271) The identification of slip planes etc. with 2–16% deformation support the previous explanation of the formation of cold-rolling textures.

Substructure characteristics of fine-grained metals and alloys disclosed by X-ray microscopy and diffraction analysis S. Weissmann (*PB* 140756, 1958, Aug. 15, pp.34; from *US Govt. Res. Rep.*, 1959, **32,** Sept. 11, 370) Quantitative information is obtained, using a special technique of reflection X-ray microscopy, on lattice misalignment of the grains, size of, and disorientation between sub-grains, lattice misalignment with sub-grains, and the nature of low-angle boundaries.

The effect of arsenic on the phase transformation of carbon steel D. S. Kazarnovskii and T. M. Ravitskaya (*Izvest. AN, SSSR, OTN, Metallurg. i Topl.*, 1959, (6), 83–91) Increasing the As content from 0·18 to 0·36% in high-carbon steels (0·78–0·92%C) results in a considerable increase in the size of the austenite grains at about 1000° and in the speeding up of the isothermal decay of the austenite. The hardenability when quenching from temp. 80–100° above the Ac_3 point is also reduced.

Regarding the hypothesis of phase transformation observed in the Kravz-Tarnavsk zone M. V. Rastegaev (*Metalloved. Term. Obra. Met.*, 1959, (12), 19–23) Two opinions have taken shape as to the formation of the Kravz-Tarnavsk zone (*ZhRMO*, 1928, (3)), (*a*) the strip is not hardened martensite, hence its formation temp. lies below the critical A_1 point; (*b*) it consists of non-acicular martensite formed after quenching from temp. above A_1. It has been shown experimentally that the conditions for the formation of non-acicular martensite are a high rate of heating to temp. above A_1, and rapid quenching. The chemical non-uniformity of the zone is observed in the microvolumes and is due to incomplete transformation of the original phases into austenite and to its incomplete homogenization.

Special features of the phase transformation in different melts of chromium nickel steels S. M. Baranov and E. M. Lukhina (*Izvest. VUZ Chern. Met.*, 1959, (6), 75–80) The melting process greatly affects phase transformations of steels. The different features of the phase transformations in different melts of Cr–Ni steels are due to the different surface contents and therefore to the different processes occurring during heating and cooling. A difference in the hardness and structure of specimens after isothermal treatment has also been established at temp. between 450–650° and at 700°.

The change in the phase composition of type 18–8 steels as a function of temperature and degree of deformation A. N. Chukhleb and V. P. Martynov (*Metalloved. Term. Obra. Met.*, 1959, (9), 44–46) This study aims at investigating the effect of low temp. deformation on the properties of some Cr–Ni austenitic steels. Three such steels have been examined and results for yield point, UTS, and for other mechanical and physical characteristics are tabulated.

Lattice parameters of iron–chromium alloys and study of the sigma phase in alloy steels (*Nat. Met. Lab., Ann. Rep.*, 1958–9, 2–3) Study of lattice parameters shows that these vary in an unexpected fashion and can also throw light on certain fundamental aspects of alloy formation. The technique of zone refining was used to prepare pure metals and preliminary experiments were conducted using Al of commercial purity.

Phase composition of isothermally hardened specimens S. N. Krasotskaya and M. N. Ponomareva (*Izvest. VUZ Chern. Met.*, 1959, (9), 111–114) The phase composition of isothermally hardened steels is similar to that which forms after quenching and tempering. It is more complex than some investigators maintain. In addition to cementite in the isothermally hardened specimen different iron carbide phases appear viz: ε and ψ Fe_5C.

Transformation is faster with controlled cooling (*Steel*, 1960, **146,** April 4, 156) The introduction of heated isothermal pits at Timken Roller Bearing Co. is described. These effect isothermal transformation of blooms in one or two days, compared with 10 or 12 days in the unfired pits previously used.—D.L.C.P.

Formation of flake graphite eutectoid R. P. Todorov and G. I. Koshovnik (*Metalloved. Term. Obra. Met.*, 1959, (9), 47–48) It was found experimentally, *inter alia*, that the following conditions are required for the formation of the flake graphite eutectoid: solidification of the cast iron in the metastable system and the absence of any secondary eutectoid graphite in the structure right up to the eutectoid temp. interval, a high silicon content (3·5–4·5%) and a moderate cooling rate (normal dry sand moulds).

The effect of silicon on the graphitization of commercial white cast iron F. K. Tkachenko (*Izvest. VUZ Chern. Met.*, 1959, (10), 131–138) A sharp increase in the metastability of cementite in the individual microvolumes results in a speeding up of its decomposition and in the appearance of an increased number of graphitization nuclei in the presence of silicon. The calculations of activation energy show that in the cast iron investigated, an increase in the Si from 0·7 to 1·7% reduces this energy from 78600 to 58600 kcal/mol. The effect of Si on graphitization is therefore the opposite of that on the activation energy of the diffusion of carbon and of recrystallization in the Fe–Si–Fe_3C system.

Relation between the α-phase due to cold working and the parent austenite, in 18/8 steels low in carbon P. Bastien and R. Margerand (*Rev. Mét. Mém. Sci.*, 1959, **56,** Oct., 463–470) This phase (α_e) appeared in an unstable austenite, already oriented by 10–20% plastic

deformation, and is already oriented on formation. Relationships between this phase and the γ-phase are derived, and it is shown on removal of surface stresses that a surface phase α_s is obtained, identical with the α_c-phase.

The diagrams of the austenite transformation in 40KhG steel (*Supplement to Metalloved. Term. Obra. Met.*, 1959, (9), 31–38) Chemical composition: 0·44%C, 0·22%Si, 0·8%Mn, 0·03%P, 0·023%S, 1·04%Cr, 0·17%Cu, 0·0 4% Mo, 0·26%Ni, <0·01%V. Critical points: Ac_1 745°, rate of heating 3°/min, Ac_3 790°, rate of heating 3°/min, M_N 355°, rate of heating 3°/min. Rate of cooling (from Ac_3 to 500°) for austenization at 840°; to obtain martensite >37°/sec; to obtain 50% martensite 8°/sec; to precipitate ferrite <7°/sec; to obtain a ferrite–pearlite structure >1°/sec.

Structural features of the transformation of austenite into pearlite E. I. Mirovskii (*Izvest. VUZ Chern. Met.*, 1959, (9), 115–118) Experiments were carried out with carbon steel of eutectoid composition (0·8%C). The specimens were heated to 1000° for 1 h and then transferred to a second furnace heated to 700°. As soon as the specimens attained the temp. of this furnace, they were removed (every 30 sec) and rapidly dipped in water. Under the microscope the formation of pearlite can be followed. At temp. below A_1 the kinetic energy of the iron atoms falls below the critical value and the interatomic attraction forces increase. Under this influence the transformation of austenite begins which results in the formation of pearlite and cementite crystals according as the iron or carbon atoms predominate in the eutectoid state.

The effect of alloy elements and carbon on the kinetics of the decomposition of supercooled austenite B. A. Apaev (*Izvest. VUZ Chern. Met.*, 1959, (10), 113–129) The isothermal decay of supercooled austenite is related to the problem of the determination of the causes complicating the kinetics of its transformation in a number of alloys. One of these is the effect of alloy elements on the polymorphous γ–α transformation. In the presence of different alloy elements the action of carbon is not the same. Complication of the kinetics is observed, with a small carbon content, in the presence of Mo, Mn, W, V, and with slightly larger quantities of Si. In nickel steels (with 4%Ni) this complication of the kinetics is not observed.

The effect of a high hydrostatic pressure on the transformation of austenite into martensite in iron nickel alloy N. A. Smirnov (*Izvest VUZ Chern. Met.*, 1959, (9), 119–123) A special apparatus was constructed for the study of this phase transformation. The initial transformation temp. is displaced by 15° for each 1000 kg/cm² pressure. Up to a pressure of 3000 kg/cm² this displacement is due to thermodynamical factors and not to a changed rate of transformation. High hydrostatic pressure makes possible the supercooling of austenite and this should prove of great interest in the practice of heat treatment. ((10), 109–112) An apparatus is described for applying a high hydrostatic pressure and also a method of direct observation of the transformation processes of martensite into austenite at temp. of from −120 to +500°. In the alloy investigated the transformation temp. is displaced 25° for every 1000 kg/cm² pressure.

The crystallography of the austenite–martensite transformation. The {111} shear solutions M. S. Wechsler, T. A. Read, and D. S. Lieberman (*Trans. Met. Soc. AIME*, 1960, **218,** April, 202–207) The graphical method is applied to the austenite–martensite transformation. The undistorted planes are determined for the lattice invariant shear on the (111) austenite plane. The solutions are discussed in terms of their degeneracy and their applicability to the formation of (225) martensite in steel.

Study of isothermal transformation characteristics of some Indian steels (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 8–9) This note describes the use of a dial gauge dilatometer. For fast transforming steel the metallographic method is used to determine the Ms temp.

Phase transformation in iron alloys S. A. Eliseev and B. G. Livshits (*Metalloved. Term. Obra. Met.*, 1959, (9), 42–43) Certain single-phase alloys showing a uniform solid solution at high temp. do not maintain this uniformity in cooling. Examples of these are the self-ordering solid solutions and the solutions in which at low temp. the stable condition known as the K state is observed. Different iron alloys containing V, V+Mo, and V+Al were investigated by quenching in water from 1150° and then keeping them 4 h between 350 and 650°. Results for individual specimens are shown graphically.

Aspects of Japanese studies on the method for austenitic grain size control A. Adachi and K. Mizukawa (*Tetsu to Hagane*, 1959, **45,** Sept., 1087–1089).—K.E.J.

The fine structure of the intergranular transition zones of technical iron B. S. Kasatkin and G. F. Darovskii (*Fiz. Met. Metalloved.*, 1959, **8,** (6), 881–884) The hypothesis of an amorphous nature of the intercrystalline zones has met with lively opposition. The conclusions of McClean (*Grain Boundaries in Metals*, London, 1957) and of other investigators have been put to the test by investigations with the electron microscope on specimens of hot-rolled technical iron, hot forged, and tempered for 3 h up to 1100° and then slowly cooled in a furnace. The pictures obtained seem to confirm the hypothesis of Arkharov (*Trudy Inst. Fizika Metallov., UF, AN, SSSR*, 1955, (16), 7) and suggest the possibility of rendering more precise the model used by the author.

Reticular substructure of ferrite grains and its effect on the deformation and failure of technical iron B. S. Kasatkin (*Izvest. AN Metallurg. i Topl.*, 1959, (3), 62–69) The formation of the ferrite α-lattice (sub-granular boundaries) in technical iron is determined by the conditions of the heat treatment. A rapid cooling results in the elimination of the reticular substructure. A slow cooling promotes an increase in the sizes of the individual α-lattice nuclei and the thickening of the fibres composing such lattice. The principal cause of the formation of the α-lattice is the plastic deformation occurring during the γ–α transformation.

Observations of the microstructure of bearing steel at elevated temperature by gas etching T. Arakawa, S. Oda, and T. Yamamoto (*Tetsu to Hagane*, 1959, **45,** Sept., 995–996) Etching by HCl gas is used to study structures arising from spheroidizing and austenitizing treatments.—K.E.J.

The pattern of intercrystalline distribution of the elements in metallic alloys A. S. Zab'yalov and B. I. Bruk (*Fiz. Met. Metalloved.*, 1959, **8,** (3), 349–361) The experiments here described justify certain conclusions among which are that, if for for a given temperature the content of an element in an alloy does not exceed its limiting solubility in the solvent metal, this element will distribute itself relatively uniformly over the entire volume of the crystal. If on the other hand the content of this element exceeds its limiting solubility, the excess will concentrate along the crystal boundaries, forming either a phase enriched by this element or else it will be present in a free state in the structure.

The effect of copper on the recrystallization temperature of mild steels M. Žídek (*Hutn. Listy*, 1959, **14,** (11), 943–947) Heavily worked steel, which recrystallizes on 5 h anneals at 520–535°C, does so only at temp. 10–15°C higher if Cu is present in amounts only slightly exceeding 0·2%, its solubility limit. With Cu contents as high as 0·5% the recrystallization temp. rises to 600°. The effect is ascribed to the precipitation of Cu from solid solution.—P.F.

Some features of the recrystallization of transformer steels with rapid heating. II. The kinetics of texture formation P. D. Izbranov, V. A. Pavlov, and N. M. Rodigin (*Fiz. Met. Metalloved.*, 1959, **8,** (3), 434–439) Some of the conclusions reached in this work may be summarized as follows: During recrystallization two types of structure are formed in greatly deformed transformer steel with a clear deformation structure, the appearance of recrystallization centres is observed with an orientation which corresponds most probably to that of the deformed crystals. Hence the texture of the first stage of recrystallization is similar to the deformation structure. Thereafter the recrystallization of this texture changes into the type usually observed in transformer steels under isothermal anneal.

Investigating deformation and recrystallization structure of the iron–nickel alloy (48%Ni) as related to the degree of deformation with cold rolling M. M. Borodkina and N. P. Gromov (*Fiz. Met. Metalloved.*, 1959, **8,** (5), 761–769) The degree of orientation changes with increasing deformation. After annealing, the cubic recrystallization structure is observed only when, as a result of deformation, a texture with intense components (110) [1$\bar{1}$2] and (110) [3$\bar{3}$5] is produced, which corresponds to a degree of deformation of 99%. Any further increase in deformation results in a weakening of the above orientation, and after anneal, in a weakening of the cubic recrystallization texture (100) [001] and in a reduction of magnetic properties.

Liquidus and solidus relations in iron-rich iron–carbon alloys R. A. Buckley and W. Hume-Rothery (*JISI*, 1960, **196,** Dec., 403–406) [This issue].

Determination of ferrite in grey-iron J. Csuka (*Koh. Lapok-Öntöde*, 1959, **10,** July, 171–172) In grey-iron piston-rings, the Hungarian standard does not permit more than 5% ferrite. In order to determine quickly the ferrite content, micro-sections are compared with suitable patterns.—P.K.

Influence of pressure from all sides on structural transformations in steel W. Jellinghaus and H. Friedewold (*Arch. Eisenh.*, 1960, **31,** May, 309–317) It is shown by three examples that such pressures influence the transformation rate of unstable and supersaturated solid solutions, the examples being the isothermal decomposition of a C-rich austenite, carbide precipitation from manganese steel and martensite decomposition in the third tempering stage.

Effect of small copper and arsenic contents on the transformation behaviour and strength properties of a 0·45% carbon steel A. Rose and A. Krisch (*Stahl Eisen*, 1960, **80,** July 21, 1007–1017) Samples containing 0·01–0·6%Cu or 0·01–0·23%As were used for the study of the transformation behaviour and strength properties of a steel containing 0·45%C. Up to 0·2%Cu has the same effect on transformation as Mn, further increase in the Cu level has—in contrast to Mn—no effect. As has no effect on transformation. Both elements brought about an increase in tensile strength, the optimum addition being between 0·1–0·2%, higher additions are no advantage. In the range of concentration studied no ill effect on the strength properties was found that could be attributed to the addition of either Cu or As.

Magnetic determination of retained austenite in hardened steel specimen A. Szombatfalvi (*Koh. Lapok.*, 1959, **14,** Oct., 445–447) The specific magnetic saturation of a steel specimen is measured with the magnetic balance of H. Lange, first after quenching, then after cooling to −190°C. From the two results, the amount of retained austenite that has been transformed at −190°C can be calculated.—P.K.

Variation of magnetic moment with composition in the iron–vanadium sigma-phase D. Parsons (*Nature*, 1960, **185,** March 19, 839–840) A letter.

On the imperfections in martensite and their relation to the formation of martensite H. M. Otte (*Trans. Met. Soc. AIME* 1960 **218,** April, 342–351) Certain choices for the shear elements of the inhomogeneous distortion in the phenomenological theory of martensite formation are examined for their agreement with crystallographic and X-ray data of iron alloys. The assumption that the shear elements must represent slip or twinning systems characteristic of b.c.c. metals is found to cover all observations, even when a small uniform dilation is taken into consideration. In b.c.t. martensite, (011) becomes a possible twinning or faulting plane in addition to (112), and qualitatively similar X-ray broadening is to be expected from both.

The martensite transformation in steels A. P. Gulyaev (*Metalloved. Term. Obra. Met.*, 1959, (11), 5–13) Some recent experimental data confirm the truth of the stress theory of martensite transformation (the stress theory postulates that the surmounting of the energy

barrier is ensured by the appearance of stresses in the austenite lattice displacing the atoms from their equilibrium positions), i.e. of the displacement mechanism accompanying the martensite crystal formation. The kinetics of martensite transformation are described by the curve of martensite formation characterized by a quantitative relation between the martensite and any such factors as temp. etc.

The behaviour of internal friction associated with the process of martensite-type transformation Wang Yeh-ning and Chu Chiang-chung (*Scientia Sin.*, 1960, **9,** Feb., 197–212) [In English] Work on the process of the martensite and reverse martensite transformations in Fe–Mn alloys shows that the magnitude of internal friction depends on the amount of transformation product in one cycle of vibration, and only under suitable conditions is it proportional to the rate of transformation. The mechanism of production of internal friction accompanied by phase change is discussed.—K.E.J.

Change in strength and plasticity indices in the direct and reverse martensite transformation M. E. Blanter and A. K. Mashkov (*Metalloved. Term. Obra. Met.*, 1959, (11), 13–19) The investigation of the plasticity of austenitic N22G2·5 and of 115G4 alloys by means of linear tensile stresses shows a sharp increase in plasticity during martensite transformation. A direct relation has been found between the rate of martensite transformation and the increase in plasticity. Data have been obtained regarding the anomalous reduction in the resistance of the metal to plastic deformation during the reverse martensite transformation.

Non-uniformity of the martensite of 30KgGS steel after high-frequency hardening Ya I. Spektor and A. P. Gracheva (*Metalloved. Term. Obra. Met.*, 1959, (9), 12–17) The method selected for induction heating ensures the production of a solid solution in which the C non-uniformity differs very little (by 10–15%) from that observed in hardening in the furnace (900°). The method described may be used for heat-treating essential components made from this steel and the tempering can then follow exactly as after heating in the furnace.

A technical note on the distribution of chromium between carbide and matrix in iron–carbon–chromium alloys J. Ballinger, I. C. H. Hughes, and T. Mulvey (*BCIRA Res. Dev.*, 1960, **8,** March, 232–237) The Cr content of the carbide and the matrix has been determined in four alloys containing about 3% and 2·5% to 9·5%Cr using electron probe micro-analysis. It was found that the Cr was distributed between the carbide and the matrix in such a way that the carbide contained three to four times the Cr content of the matrix. Some details of the technique are discussed.

The ternary system iron–silicon–tin R. Vogel and H.-J. Jungclaus (*Arch. Eisenhütt.*, 1960, **31,** April, 243–258) Taking into account the most recent work on equilibria in the iron-rich part of the Fe–Sn system, and by means of thermal analysis and structural investigation, the complete Fe–Si–Sn phase-diagram is constructed and discussed in detail.

The constitutional diagram of the $TiFe_2$–V system Bi Tsin-Kua and I.I. Kornilov (*Izvest. AN, SSSR, OTN, Metallurg. i Topl.*, 1959, (6), 110–112) By means of thermal and microstructure analysis as well as hardness measurements of alloys of this system it has been possible for the first time to study and construct the constitutional diagram of the $TiFe_2$–V system. It has been established that this system is quasi-binary. The eutectic is formed at the m.p. of 1400°. Reciprocal solubility of the components occurs in this system and therefore there are two single phase domains (γ_1 and β) and a binary phase ($\gamma_1+\beta$). The solid solutions gradually increase in hardness with increasing V content.

Solubility of silicon carbide in iron–silicon alloys V. A. Kravchenko and S. I. Khitrik (*Stal'*, 1960, (6), 520–522) A study of solubilities with higher Si contents has been made. Empirical equations for the system are given.

The ternary system iron–silicon–beryllium R. Vogel and H.-J. Geske (*Arch. Eisenh.*, 1960, **31,** May, 319–330) A detailed description of the phase diagram is given, and the existence of two hitherto unknown ternary phases FeSiBe and $FeSiBe_2$ is shown (12 refs).

CORROSION

The modern theories of the mechanism of the corrosion of metals, in particular of steel H. Grubitsch (*Radex. Runds.*, 1960, June, 159–172) The corrosion of metals is very complex and no straightforward, generally applicable theory exists. Protection can only be achieved if the cause of the corrosion is sufficiently known, this requires research in each particular case. Because of the far-reaching economic consequences of corrosion the need for more corrosion research in Austria is stressed.—T.G.

Corrosion (*SAE J.*, 1960, Feb., 32–34) A brief survey of some American motor-car manufacturers' methods of corrosion prevention in motor-car bodies. The article illustrates the divergence of practices but anticipates freer exchange of information.—A.H.M.

The corrosion of iron and steel J. C. Hudson (*Railway Steel Topics*, 1960, **5,** (3), 23–32) Modern knowledge of the corrosion of iron and steel and its prevention as affecting railways is presented in the light of the Sixth Report of the BISRA Corrosion Committee. Subjects discussed include atmospheric corrosion, correct painting technique, the use of metal coatings beneath paint, the corrosion of buried metals and of harbour installations which can often be checked by cathodic protection, and the corrosion of steel reinforcements in concrete which can be avoided by correct design and good practice.

Studies on the corrosion of stainless steels in high temperature and high pressure water. (1) Early stage of corrosion T. Yanagihara, G. Shimoka, S. Ideka, and K. Tomita (*Trans. Nat. Res. Inst. Met.*, 2959, **1,** (2), 126–132) Six commercial types of stainless steels were examined in high-purity water at 200°C at 15 kg/cm² and at 300° at 90 kg/cm² for 10–120 h. The products in the early stages of corrosion are identified.

A model of the mechanism of electrochemical conversion from active to passive states W. A. Mueller (*J. Electrochem. Soc.*, 1960, **107,** 57–164) A model of the mechanism of passivation of metals by oxide films is explained by equations which describe the density of the anodic dissolution current as a function of the pH and the potential difference between the metal and the electrolyte. A simple method derives all the constants required for the mathematical formulation of the anodic dissolution current from experimental data.—S.H.-S.

Caustic cracking in mild steel for boilers. Part II (*Calore*, 1959, **30,** Feb., 61–71) A detailed examination is made of the phenomenon and conclusions are drawn as to the conditions which cause crack formation.

Corrosion and packaging J. Baudin (*Usine Nouv.*, 1960, May, Special No., 232, 237, 239–241, 243–245, 247–249) General principles of corrosion are discussed and the use of inhibitors, cleaning methods, and choice of method of protection in packing are considered with special reference to metals.

The corrosion and protection of iron and steel H. C. Bryson (*Austral. Eng.*, 1959, **52,** Dec., 99, 101, 103, 105, 123, from *Vickers Overseas News*) A general review of corrosion rates and paint protection.

Corrosion in the oil industry H. M. Powell (*Corr. Prev.*, 1959, **6,** Oct., 46–48) Oil well problems involving corrosion in gathering systems, long distance pipelines, storage tanks, jetties and submarine lines, tanker problems, refinery protection, and distribution arrangements are briefly reviewed.—S.H.-S.

Marine corrosion and marine paints T. A. Banfield (*Chem. Ind.*, 1960, May 21, 524) The report of a lecture.

Stress corrosion and grain boundary type F. Erdmann-Jeanitzer and G. Hötzsch (*Werks. Korros.*, 1960, **11,** April, 212–216) The examples are non-ferrous.

Corrosion problems encountered in the burning of sulphur-bearing fuels in oil-fired burners and methods of alleviation: 2 H. N. Wigan (*Corros. Prev.*, 1959, **6,** Oct., 60–64) Chemical control methods, including the neutralizing and inhibition of SO_3, and for small and medium-size oil-fired boilers, the use of fuel additives are described.—S.H.-S.

Some aspects of the corrosion of decorative coatings F. A. Lowenheim and W. H. Rowan (*Proc. Amer. Electropl. Soc.*, 1959, **46,** 205–210; discussion 379) The beneficial effects of Cr coatings thicker than 0·00001 in., of the use of 12%Sn bronze instead of Cu as an undercoat and the superior corrosion resistance of Sn–Ni alloy deposits are described.—A.D.H.

On the relation between the work function and the corrosion rate of the metals S. Shimodaira (*Nippon Kinzoku*, 1959, **23,** April, 243–246) The relationship between the thermoionic work function and corrosion rate is derived from the theory of absolute electrode potential. With activation-controlled corrosion, the corrosion rate of common metals is roughly inversely proportional to the work function (16 refs).—K.E.J.

Corrosion inhibition and the zero charge potential of metals D. M. Brasher (*Nature*, 1960, **185,** March 19, 838–839) A letter. The value for mild steel is obtained and used to interpret inhibition mechanism in solutions in equilibrium with air. The discussion has special reference to benzoate.

Crystal growths and the corrosion of iron E. A. Gulbransen and T. P. Copan (*Nature*, 1960, **186,** June 18, 959–960) Crystal habit of oxide whiskers is considered, as shown by electron micrographs.

Mechanism of stress corrosion of austenitic stainless steels in high-temperature chloride waters R. W. Staehle, R. H. Beck and M. G. Fontana (*PB* 138562, 1958, April, pp.33; from *US Govt. Res. Rep.*, 1959, **32,** Sept. 11, 368) A study of stress-corrosion cracking of this material under various conditions of stress, chloride concentration, immersion, wetting, and presence of O_2. A mechanism of stress-corrosion cracking is proposed (13 refs).

Corrosion of metals in tropical environments. Part 4: wrought iron C. R. Southwell, B. W. Forgeson, and A. L. Alexander (*NRL Rept.* 5370; *PB* 151852, 1959, Oct., pp.15) Exposures in fresh and sea water, mean tide, inland, and marine atmospheres for eight years are reported. The weight loss was less than that for steel and, when coupled to wrought iron the corrosion of steel was halved in underwater tests. In a marine atmosphere the corrosion was 1·6 times that of inland atmosphere, in both the steel was less heavily corroded than the wrought iron.

Fireside corrosion in oil-fired boilers L. K. Rendle, R. D. Wilsdon, and G. Whittingham (*Corr. Prev. Control*, 1960, **7,** June, 37–48) Tests on a small furnace were carried out using various types of oil fuel and examining flue gas and combustion product composition (SO_3) at high and low temp. Methods of control were then considered with special attention to NH_3 injection.

Corrosion problems in the Lacq sour gas field M. Estavoyer (*J. Inst. Petr.*, 1960, **46,** July, 223–233) Initial design and behaviour of installations and subsequent improvements are described.

Corrosion and staining of stainless steel knives E. A. Oldfield and D. Twigg (*Corr. Prev. Control*, 1960, **7,** June, 34–36, 58) Staining in contact with Al or Zn in tap water and pitting corrosion were studied with addition of proprietary detergents.

Contribution to the study of the corrosion of a low-carbon unalloyed steel by crude Lacq gas J. A. Ternisien, A. Servasier, and S. Barbezat (*Compt. Rend.*, 1960, **250,** Feb. 15, 1267–1269) The corrosion products formed by the action of the high-S crude Lacq natural gas are described and their composition discussed.

Lead contamination—new corrosion villain C. L. Leithauser (*SAE J.*, 1960, March, 37) An account is given of various tests with rimming steels which show that Pb deposited on steel surfaces reduces corrosion resistance by preventing the formation of a good phosphate coating.—A.H.M.

Steel tubes and the gas industry (*Gas World*, 1960, **151,** May 14, 758–759) A general account of gas pipe laying over long distances.

Recommendations for the laying of steel gas

service pipes (*Inst. Gas. Eng. Publ. No.* 563, 1959, Dec., pp.24).

Effects of soil corrosion on cast-iron pipe H. L. Hamilton (*J. Am. Water Works Assoc.*, 1960, **52,** May, 638–650) Surveys of buried pipes in many parts of the US with an assessment of soil corrosivity are given. Stray electric currents, aggressiveness of the environment, and previous history of structures in the area need to be considered.

Corrosion of stainless alloys in high-temperature nitrogeneous environments D. L. Keller (*BMI*–1361, 1959, July, pp.49; from *US Govt. Res. Rep.*,1959, **32,** Nov. 13, 649) No abstract.

Experiments on erosion of steel by propellant gases using vent technique R. N. Jones and E. R. Weiner (*PB* 134285, 1957, Mareh, pp.41; from *US Govt. Res. Rep.*, 1959, **31,** Jan. 16, 41) A brief discussion of development of this technique with the more significant results.

Scale formed during heating M. Reinhold (*Koh. Lapok.*, 1959, **14,** Aug., 381–383) The adhesion of scale affects significantly the quality of the surface of the rolled steel products. This property depends on the chemical composition and physical structure of scale. These are, on the other hand, results of the combustion process in the heating furnace and can be controlled accordingly.—P.K.

Oxidation of experimental alloys J. C. Richmond and H. R. Thornton (*WADC TR* 58–164; *AD*–155688; *PB* 151264, 1958, June, pp.54; from *US Govt. Res. Rep.*, 1959, **31,** Jan. 16, 43) A study of the oxidation resistance of ten high-temp. alloys, all of which conformed reasonably well to the parabolic rate law in weight-gain oxidation tests.—S.H.-S.

Marker movements in the oxidation of iron and some other metals R. F. Tylecote and T. E. Mitchell (*JISI*, 1960, **196,** Dec., 445–453) [This issue].

An X-ray high-temperature oxidation study on iron–copper H. J. Goldschmidt (*JISI*, 1960, **196,** Dec., 390–393) [This issue].

Autoclave testing of type-430 stainless steel J. W. McGrew (*MND–E*–1602; *AD*–209930; *PB* 142695, 1959, Jan., pp.26; from *US Govt. Res. Rep.*, 1959, **32,** Nov. 13, 620) Stressed specimens of AISI type-430 stainless steel were subjected to corrosive environments in rocker-type autoclaves at 400°F and 200 psi for periods generally of 120 h duration. The most important environmental controls included concentration of oxygen, chloride, and phosphate. The pH was controlled between 8·5 and 11·5.—S.H.-S.

Comparative data on the corrosion resistance of selected types of 18–8 chromium–nickel stainless steels K. L. Sanborn (*HW* 32727, 1954, Aug., pp.27, from *US Govt. Res. Rep.*, 1959, **32,** Sept. 11, 405) (No abstract).

Corrosion investigations on a sintered alloy with 60%Ni, 20%Fe and 20%Mo H. J. Booss (*Arch. Eisenh.*, 1960, **21,** March, 195–197) Cold rolled sheets of the alloy were found to be resistant to corrosion by concentrated acids, but were attacked by more dilute acids. Strong attack was also found in cyclic tests in air with various moisture SO_2 and CO_2 contents, and in salt-water spray and immersion tests.

Pitting on investment-cast corrosion resistant steels L. W. Duffen and O. C. Jarman (*Brit. Found.*, 1960, **53,** Feb., 79–81) The pitting of cast Cr and Cr–Ni steels was investigated and found to be a liquid iron oxide–silica reaction product and occurs after solidification of the castings. Cooling in an oxygen-free atmosphere prevents pitting.—A.D.H.

Stress corrosion cracking of austenitic stainless steels W. B. Brooks (*Corrosion*, 1959, **15,** Sept., 103–110) The generally accepted causes of stress corrosion cracking in stainless steels are reviewed, and the design of heat exchangers intended for use with chloride-containing waters is considered. The theoretical considerations involved are outlined.—G.F.

Clogging and corrosion of the blades of gas-turbine plants in iron and steel works H. Pfenninger (*Stahl Eisen*, 1960, **80,** June 9, 796–801) In spite of the perfection of the modern gas turbine, in the long run clogging and corrosion of the compressor and turbine blades are a serious problem. The causes are enormous quantities of gas and air that has to be handled by the turbine. Clogging and corrosion are explained.—T.G.

Colloquium on metallurgy and discussions of corrosion for nuclear energy P. Orlowski (*Corros. Anticorr.*, 1959, **7** Dec., 440–441) A brief exposition of subjects discussed at the Centre of Nuclear Studies at Saclay, with a reference to researches on the subject of corrosion.—S.H.-S.

Corrosion processes in carbonated beverage cans E. L. Koehler, J. J. Daly jun., H. T. Francis, and H. T. Johnson (*Corrosion*, 1959, **15,** Sept., 477t–482t) A description is given of work undertaken to minimize the occurrence of perforations and excessive iron pick-up in carbonated beverage cans. The mechanism of this type of corrosion is discussed.—G.F.

Bacterial activity at the bottom of backfilled pipe line ditches J. O. Harris (*Corrosion*, 1960, **16** March, 149t–154t) The author compares bacterial activity at the bottom of backfilled pipe line ditches with that found in normal undisturbed soil, and discusses factors affecting bacterial development. The role played by bacteria in the deterioration of pipe line coatings is described.—G.F.

The oxidizability of steels and cast irons at high temperatures E. M. Blank (*Metalloved. Term. Obra. Met.*, 1959, (12), 53–54) Si reduces to a large extent the oxidizability of steel at high temp. and so the addition of Si is in many cases more effective than the same amount of Cr. The oxidizability, the growth, and the failure of normal cast iron at high temp. is related to the lamellar form of the graphite, which damages the compactness of the metallic matrix. The graphite oxidizes and burns away and the resulting cavities promote the failure of the material by the hot gases.

Observations on the Fe–Cr–O system A. U. Seybolt (*J. Electrochem. Soc.*, 1960, **107,** March, 147–156) An isothermal section for equilibrium conditions at 1300°C in the Fe–Cr–C system which, with a minor modification, holds for 1000°C, shows that two types of equilibrium scale are formed on Fe–Cr alloys: spinel or iron chromite below 13%Cr, and Cr_2O_3 containing a little dissolved Fe_2O_3 at higher Cr contents. Experimental methods and results are discussed in detail. Pt wire marker experiments show that the Cr_2O_3 on 20 or 30%Cr–Fe alloys forms almost entirely by cation (Cr^{+3}) diffusion.—S.H.-S.

Over-temperature in metal scaling D. Caplan (*J. Electrochem. Soc.*, 1960, **107,** April, 359–360) This note briefly describes an investigation of certain alloy steels aiming at determining overtemp. directly with a thermo-couple welded to the surface of the specimen. Graphically reproduced temp./time curves show that large over-temp. occur when the iron is oxidized. Details of six runs are summarized. Overheating will be less if conditions are such as to decrease the reaction rate, increase the heat capacity of the specimen, or remove heat more efficiently from it.

Electron diffraction studies on the high-temperature oxidation of iron–aluminium alloys T. Nakayama (*Waseda Univ., Rep. Casting Res. Lab.*, 1958, (9), Nov., 71–80) [In English] Data are given for the structure of surface films formed on various alloys at various temp. The heat-resistance of calorized steel is caused by the formation of γ-Al_2O_3 films on the surface in the initial stage of oxidation below 1000°C. Two reactions leading to the formation of Al_2O_3 are examined.

Mechanism of the iron–hydrogen sulphide reaction at elevated temperatures H. Arm, P. Delahay, C. Hudgins, F. Hügli, L. Hulett, and M. Qureshi (*J. Electrochem. Soc.*, 1960, **107,** April, 264–271) The mechanism of the Fe–H_2S reaction was studied at 500–700° for a total gas pressure of 1 atm. The rate of attack was essentially constant and the corrosion scale was composed of two layers, a thin dense layer, adjacent to the metal and a porous layer with a coarse crystalline structure. These are interpreted from two main effects, partial blocking of reaction at a constant number of reaction sites; and continuous recrystallization of the dense scale into a porous scale offering no barrier to transport of reactants. This mechanism is self-regulating.

Corrosion resistance of vitreous enamel N. S. C. Millar (*Vitr. Bull.*, 1960, **10,** April, 345–350) Resistance to acid, alkali, and detergent is discussed.

The behaviour of 18–8 stainless steel in 20° Bé HNO_3 containing chloride A. Prati (*Chim. e Indust.*, 1960, **42,** Feb., 145–150) The results are described of laboratory tests carried out to determine the lowest chloride content compatible with the corrosion resistance of the material in an HNO_3 absorption vessel with acid of the concentration 20° Bé. The minimum chloride content tolerable was found to be 9·2 g/l.

Laboratory experiments on the corrosion-reducing influence of the cooling of high-grade steels in hot, concentrated sulphuric acid H. Holdschick and L. K. Bittner (*Werks. Korr.*, 1960, **11,** April, 216–219) Experiments carried out on tubular bends of 18–8–2 Cr–Ni–Mo steel are described, in which the influences of wall thickness, acid attack, and temp. difference between coolant and agent were investigated. A very marked improvement in resistance to corrosive attack in the case of the cooled material was observed.

Studies on corrosion (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 10) Brief descriptions are given of studies on atmospheric corrosion of various metals and alloys, corrosion of cast iron by fused caustic soda, corrosion of a pump impeller, erosion of an induced draught fan at a power station and brown spot defects on Al discs.

The influence of movement and temperature on the corrosion of mild steel. I. Water circulation apparatus and tests in Teddington mains water G. Butler and H. C. K. Ison (*J. Appl. Chem.*, 1960, **10,** Feb., 80–93) An apparatus for investigating corrosion in flowing water at speeds up to 400 ft per min and at temp. up to 70° is described. Each system accomodates 36 tube specimens, each 6 in. long, and provides for three speeds of flow. Preliminary conditioning tests with a hard mains water demonstrate the applicability of the testing technique. The corrosivity of this water is largely governed by its scale forming properties and on increase in both speed of flow and temp. promotes the deposition of a protective scale. The decrease of alkalinity due to scale deposition often results in a higher corrosion rate on specimens introduced into the system during test.—S.H.-S.

The accelerated weathering of organic finishes A. A. B. Harvey (*Proc. Amer. Electropl. Soc.*, 1959, 96–103; discussion 365–366) Methods used to evaluate paint coatings by exposure to light; moisture and elevated temp. under laboratory conditions are critically reviewed. As natural exposure conditions vary so widely, the results of accelerated tests must be interpreted with caution and no prediction of service life can be made with reliability.

German standardisation practice with accelerated corrosion tests—3 B. M. Pearson (*Corros. Prev.*, 1960, **7,** Feb., 49–51, 54) The results of accelerated corrosion tests of various types, carried out at many laboratories in co-operation, on steel and zinc sheets, are presented and discussed.

Corrosion testing of electrodeposited coatings F. L. LaQue (*Proc. Amer. Electropl. Soc.*, 1959, 141–148; discussion 369) A review is given of corrosion tests in natural environments, accelerated tests, and of specialized tests used to investigate coating behaviour. The significance of the tests is discussed (37 refs).

Outdoor corrosion results with chromium–nickel–chromium plate H. Brown and M. Weinberg (*Proc. Amer. Electropl. Soc.*, 1959, 128–132, discussion 367–368) The results of outdoor and laboratory corrosion tests confirm that improved protection is given to steel and zinc-base die castings by plating with layers of Cr–Ni–Cr or Cu–Cr–Ni–Cr compared with Ni–Cr and Cu–Ni–Cr deposits. Details of plating procedures are given. The improvement is due to the action of the lower layer of Cr in diverting pits laterally into the Ni instead of allowing downward penetration into the basis metal.

Aggressiveness of water: tests of aggressiveness against metallic, stone, and organic materials (1) E. Leclerc (*Corros. Anticorr.*, 1960, **8,** Jan., 3–14) A general study on corrosion, on the composition of waters, and of

direct and indirect causes of reaction of water against ferrous metals, cements, and plastic materials.—S.H.-S.

Corrosion tests by thermal waters E. Chiostri (*Corros. Anticorros.*, 1960, **8**, Jan., 15–36) Tests are reported by Montecatini of thermal waters upon different types of materials for conveyor pipes, metallic and plastic. Materials tested comprised: (A) cement, asbestos cement, earthenware, ceramic, sandstone, and glass; (B) iron and its alloys with rustless steel; (C) other metals and their alloys: lead, tin, copper, and its alloys, zinc, aluminium, magnesium, and light alloys; (D) plastic materials, synthetic resins, and diverse materials; (E) varnishes, vitrifications, and protective treatments. Twelve detailed tables of results are given.—S.H.-S.

Experiences with the copper chloride modified acetic acid salt spray C. F. Nixon, J. D. Thomas, and D. W. Hardesty (*Proc. Amer. Electropl. Soc.*, 1959, 159–163; discussion 371–373) Experience has proved that the ASTM modified salt spray test can be used to predict the corrosion resistance of Ni–Cr plated steel at least within the first year of life in service. Modifications in plating practice that have followed the use of this disciminating test are described.—A.D.H.

Sulphur dioxide accelerated corrosion test—testing conditions and equipment J. Edwards (*Proc. Amer. Electropl. Soc.*, 1959, 154–158; discussion 370–371) Better reproducibility is obtained in the SO_2 corrosion test of the temp. is maintained at 25 ± 2°C. The construction and operation of a corrosion test cabinet is described in detail.—A.D.H.

Experience with the use of the Corrodkote test D. M. Bigge (*Proc. Amer. Electropl. Soc.*, 1959, 149–153; discussion 369–370) The development of a paste containing kaolin, copper nitrate, ferric chloride, and ammonium chloride is described. The corrosion produced on plated car parts by this material in 24 h gave a highly significant correlation with one year's exposure tests in the Detroit atmosphere.—A.D.H.

Corrosion of metals in tropical environments. Part 3. Underwater corrosion of ten structural steels B. W. Forgeson, C. R. Southwell, and A. L. Alexander (*Corrosion*, 1960, **16**, March, 105t–114t) The authors evaluate the corrosion of ten structural steels exposed to tropical sea and fresh waters for eight years, and correlate the results with those of similar tests on the east and west coasts of the USA.—G.F.

Electrode potential testing J. H. Bender jun., J. W. Dutli, and P. D. Edwards (*Nondestr. Test.* 1960, **18**, March–April, 99–102) Development and applications of a non-destructive test for ionic surface inclusions in metals and for pores through an electroplate or cladding are described. The principle involves the electrode potential difference existing between dissimilar ionic materials when immersed in a suitable electrolyte.—S.H.-S.

Electrical resistance measuring device plus statistical analysis yield unique approach to corrosion problems G. E. Moller and J. T. Patrick (*Corrosion*, 1960, **16**, March, 155t–161t) The authors describe the application of statistical techniques to the analysis of data obtained from electrical resistance measuring devices. In the particular instance discussed, the technique has permitted the operational variables affecting corrosion rate to be determined, and the calculation of an equation to predict corrosion rates.—G.F.

Corrosion and weldability studies on chromium–manganese austenitic stainless steels D. Warren (*Corrosion*, 1960, **16**, March, 119t–130t) The author describes corrosion resistance and weldability studies carried out on Cr–Mn–Ni and Cr–Mn–N austenitic stainless steels in order to determine their usefulness for chemical plant applications. The results are compared with those obtained on high-Ni stainless steels.—G.F.

Relationship of microstructure and stress corrosion cracking of type 410 stainless steel P. S. Trozzo and R. F. McCartney (*Corrosion*, 1960, **16**, March, 26–30) Three heats of type 410 stainless steel exhibiting different degrees of susceptibility to stress corrosion cracking were investigated by electron microscopy and diffraction techniques in order to relate microstructure to stress corrosion fracture behaviour. It is shown that heat treatment which breaks up the continuous network of untempered martensite in the prior austenite grain boundaries reduces stress corrosion susceptibility, but at the expense of a reduction in tensile properties.—G.F.

Environment factors conducive to graphite corrosion R. I. Higgins (*BCIRA J. Res. Dev.*, 1960, **8**, March, 217–220) Graphitic corrosion occurs where the corrosion products of the iron matrix can escape from the casting in a soluble form. If the final corrosion product is rust then it must be precipitated out of contact with the cast iron surface. The chemical and electrochemical factors which favour graphitic corrosion are described on this basis. It is also noted that a high corrosion rate is not a prerequisite for graphitic corrosion although the two effects may be interrelated in particular cases.

The corrosion behaviour of welded low alloy steel D. C. Briggs, J. U. MacEwan, and H. H. Yates (*Corrosion*, 1960, **16**, April, 205t–208t) The authors have investigated the enhanced corrosion resistance of 1%Cr steel 4130 adjacent to welds. As the cooling rate from austenitic temp. increases, corrosion resistance increases due to greater retention of Cr in the ferrite. At very low cooling rates, secondary effects associated with size and possibly shape of carbide particles act in opposition to the Cr effect. The enhanced resistance adjacent to welds is attributed to these factors.—G.F.

A laboratory evaluation of zinc anodes in sea water J. A. H. Carson, W. L. M. Phillips, and J. R. Wellington (*Corrosion*, 1960, **16**, April, 171t–177t) The authors present data on the anodic polarization of various zinc alloys in natural sea water. The combined effects of additions of 0·0003–0·0320%Fe and 0–22%Al were investigated at five controlled anode current densities ranging from 0·5 to 20 ma/in^2 for times up to 100 days. The interrelated effects of Fe, Al, current density, and time are presented by means of graphs and charts.

The inception of cavitation on isolated surface irregularities J. W. Holl (*Trans. ASME J. Basic Eng.*, 1960, **82**, 169–184) Two families of cylindrical roughness elements having constant cross-sections are studied: one having a circular-arc and the other a triangular cross-section. The theoretical minimum-pressure coefficient for the circular arc irregularities is determined as a function of the relative height of roughness for several values of the boundary layer shape parameter. Cavitation tests in the water tunnel of Pennsylvania University Ordnance Research Laboratory are described, and the results applied and conclusions recorded.—S.H.-S.

Indentation of metals by cavitation W. H. Wheeler (*Trans. ASME J. Basic Eng.*, 1960, **82**, 184–194) A review, supported by photomicrographs in monochrome and colour and followed by a discussion. The special features of the microscope technique employed to get the photographs are explained.—S.H.-S.

The influence of the silicon in cast iron on corrosive wear R. Graham, O. S. Prado, M. H. Collins, E. A. Brandes, and H. K. Farmery (*Chartered Mech. Eng.*, 1960, **7**, March, 121–122) A summary of a paper for written discussion. Diesel engine piston rings from special cast irons were tested in service.—S.H.-S.

Effect of adsorption of polar organic compounds on the reactivity of steel H. F. Finley and N. Hackerman (*J. Electrochem. Soc.*, 1960, **107**, April, 259–263) Rate studies were made for the oxygen-free reaction between steel powder and N H_2SO_4 both inhibited and uninhibited. In particular it was shown that the retardation of the reaction by organic polar compounds was influenced more markedly by molecular structure than by molecular weight or area.

Application of cathodic protection for the prevention of atmospheric corrosion D. K. Wilburn (*AD*–156373; *PB* 142325, 1958, Jan., pp.32; from *US Govt. Res. Rep.*, 1959, **32**, Nov. 13, 620) Controlled laboratory tests in a high-humidity chamber to determine the effects of cathodic protection on selected test panels. Current density measurements associated with weight loss calculations provided a quantitative measure of corrosion attack. A modified cathodic protection method, employing a self-conducting paint, was investigated as a medium of current transfer relative to corrosion inhibition.—S.H.-S.

Cathodic protection of stainless-steel waste lines. Interim Report No.1. Underground pipelines and structure corrosion study programme R. T. Jaske (*HW*–33504, 1954, Nov., pp.26; from *US Govt. Res. Rep.*, 1959, **31**, Jan. 16, 62) (No abstract).—S.H.-S.

Experiments on the prevention of pitting attack on cast iron propellers by cathodic protection—3 R. I. Higgins and H. H. Collins (*Corr. Eng.*, 1960, June, i–vi; supplement to *Corr. Prev. Control*, 1960, **7**, June) An estimate of the life and current output of shrouded anodes and of the value of high-duty coatings is made as appendices to a previous section.

Increasing the corrosion resistance through flame priming H. Ehrenberg (*Schweissen Schneiden*, 1960, **12**, May, 239–241) A novel process is described for the protection of steel surfaces. A metal salt solution is applied to the cleaned steel surfaces where it reacts with the surface forming insoluble metal compounds. By subsequent flame scarfing the thin film of metal compounds is burnt into the surface of the steel part. The resulting continuous, very thin, amorphous protective layer shows a high corrosion resistance and is well suited as primer for paint coatings.—T.G.

Corrosion protection in steel construction H. Hebberling (*Werks. Korros.*, 1960, **11**, March, 145–147) Measures to be taken in the protection of light steel structural members, including preparation of the surface, are reviewed.

Anodic and cathodic polarization phenomena in the inhibition of the acid corrosion of iron W. Machu and H. I. Morcos (*Werks. Korros.*, 1960, **11**, March, 156–162) It is shown that the inhibitors are absorbed in the first place on the local anodes, and later by the local cathodes. The consequences of this mechanism in relation to the value of inhibitors are discussed.

The struggle against marine corrosion of steel by cathodic protection and by painting M. Fonteyn (*Bull. Centre Belge d'Etude et de Documentation des Eaux*, 1958, (40), 101–102) A general discussion of principles.

Cathodic protection of an active navy tugboat with zinc anodes—42 months' service H. S. Preiser and B. H. Tytell (*Corros. Techn.*, 1960 **7**, June, 181–182; condensed from *Am. Soc. Nav. Eng. J.*, 1959, April) Experience with an American Navy tug showed the suitability of Zn anodes containing <0·0014%Fe for the cathodic protection of active and possibly inactive ships at seawater berths.

Zinc anode cathodic protection system on U.S. submarine 'Wahoo' R. C. Francis (*Corros. Techn.*, 1960, **7**, June, 183–184; from *Bureau of Ships J.*, 1959, April) Details are given of a 27-month service test in this submarine, showing that the system described gave good protection against electrolytic corrosion.

Case histories show value of corrosion inhibitor squeeze treatment R.-H. Poetker (*J. Petr. Techn.*, 1960, **12**, June, 36–40) Results of the process of pumping inhibitor into the oil-bearing formation are reviewed.

Prevention of sulphide-stress cracking in sour-condensate well equipment W. J. McGuire and L. W. Vollmer (*Trans. ASME J. Eng. for Ind.*, 1960, **82B**, 93–102) A review of operating conditions and recommendations for minimizing cracking tendencies by choice of materials and design and suitable heat-treatment for carbon and alloy steels are presented.

Effect of moisture on carboxylic acid adsorption to steel M. E. Schraer and J. L. Kalinsky (*Nature*, 1960, **186**, May 28, 710) A letter. Moisture is shown to enhance adsorption, and so to prevent rusting, more effectively than dry films of alkylsuccinic acids.

The use of corrosion inhibitors in the petroleum industry L. Cavallaro (*Corros. Anticorros.*, 1959, **7**, Dec., 417–433) Increasing use of corrosion inhibitors in the petroleum industry for the protection of extracting, refining, storage, and transportation equipment is constantly evident. The author underlines the importance of pH and the synergic action of neutralizing agents. The problem is particularly complex due to the presence of the

system of salt-water-petroleum. Factors to be considered include the dampness of surfaces to be protected, solubility, stability (dilution, heat) of the inhibitory substances. Those of a passive nature are classed as (A) direct and (B) indirect. Active neutralizing substances are also indicated; also those in vapour phase. Film forming inhibitors are reviewed, containing (1) nitrogen, (2) oxygen, (3) sulphur, (4) N and O, (5) S and O, and (6) S and N. Examples of appropriate uses are listed, with variations.—S.H.-S.

Corrosion inhibitor evaluation at elevated temperatures V. W. Maxwell (*Corrosion*, 1960, **16,** April, 201t–203t) The author presents an evaluation of commercially available organic corrosion inhibitors at elevated temp., and compares the results with those obtained at room temp. The apparatus, materials used, and test method are described.—G.F.

Corrosion inhibitors for carbon tetrachloride–water vapour atmospheres K. W. Calkins and R. W. Hawley (*Corrosion*, 1959, **15,** Sept., 447t–449t) The authors have investigated the use of various inhibitors for preventing corrosion of mild steel in CCl_4–water vapour systems, and have attempted to determine the probable corrosion mechanism. Of the 48 inhibitors tested, ethanolamine appeared to be most effective.—G.F.

Screening tests of inhibitors to prevent chloride stress corrosion J. H. Phillips and W. J. Singley (*Corrosion*, 1959, **15,** Sept., 450t–454t) The authors have carried out screening tests in tilting autoclaves to evaluate possible inhibitors for preventing chloride stress-corrosion attack of stainless steel in alkaline-phosphate boiler water containing 50 or 500 ppm of chloride. Nitrate appeared satisfactory for boiler applications, and Na_2SO_3 effectively prevented chloride corrosion cracking.—G.F.

Action of the XO_4^{n-} inhibitors G. H. Cartledge (*Corrosion*, 1959, **15,** Sept., 469t–472t) The author summarizes experimental studies on the effect of ions and molecules of the type XO_4^{n-} upon corrosion of iron and steel, and shows the competitive and reversible nature of the surface state associated with inhibition. The ways in which the presence of an adsorbed inhibitor may affect the kinetics of electrode processes at a metal-solution interface are discussed.—G.F.

Oil-soluble inhibitors for controlling corrosion in tankers and pipe lines W. S. Quimby (*Corrosion*, 1960, **16,** March, 9–18) The author discusses the causes of corrosion in the transportation and refining fields of the petroleum industry, where oil-soluble inhibitors can be used. The requirements of a good inhibitor are listed, and several particular applications are described.—G.F.

The use of heterocyclic tertiary amines for the control of corrosion caused by flue gases E. B. Davies and B. J. Alexander (*J. Inst. Fuel*, 1960, **33,** April, 163–173) The availability and origin of heterocyclic tertiary amines are indicated. Their development for the control of 'cold end' acid corrosion inhibition is traced with details of laboratory experiments followed by pilot plant tests leading to full scale installations on various types of boiler plant. The coagulating effect of these amines on stack solids is also noted together with a description of experiments carried out to assess this phenomenon. Corrosion inhibition amounting to at least 80% is claimed for air heaters and economizers.

Current densities to protect steel piling in fresh water tidal estuaries D. B. Bird and H. G. Burbidge (*Corrosion*, 1960, **16,** April, 14, 16, 18, 20) The authors discuss the unique water conditions in the tidal estuary at Port Alfred, Quebec, and their effect on cathodic protection of steel piling. The factors discussed include salinity gradient at different depths, oxygen saturation, and seasonal water freshening.

Centralized chemical feed to multiple cooling towers W. Harrison and P. G. Bird (*Corrosion*, 1960, **16,** April, 9, 10, 12, 20) The authors describe a centralized system for feeding corrosion inhibitor and acid for pH control to several cooling towers. The problems encountered and their solutions are given.—G.F.

Cathodic protection anodes for offshore structures W. A. Johnson and J. T. Condry (*Corrosion*, 1959, **15,** Sept., 112) A brief description is given of new methods of installing anodes in cathodic protection systems for offshore drilling structures. The operation of graphite anodes above the manufacturer's recommended current density is outlined.

Use of magnesium for cathodic protection of pipe lines in high resistivity soil A. W. Peabody (*Corrosion*, 1959, **15,** Sept., 497t–502t) A cathodic protection installation is described in which satisfactory protective potentials were attained on about 400 miles of enamel-coated pipeline with a total current of 2–3 amps. from 9 mg anode beds. The use of long slender anodes to obtain the necessary current output is discussed.—G.F.

Principles and criteria for cathodic protection of steel in sea water M. H. Peterson (*Corrosion*, 1959, **15,** Sept., 483t–487t) The author reviews the development of cathodic protection from the original work of Davy to the formation of an adequate theory of cathodic protection. Experimental techniques for determining criteria for protection are described, and the advantages and limitations of each are discussed (84 refs).—G.F.

Corrosion prevention by the deoxygenation of water by the desorption method P. A. Akol'zin (*Corrosion*, 1960, **16,** April, 178t–180t) Corrosion of boilers can be prevented by the deoxygenation of the boiler water by a desorption process. This process is described and the factors affecting the degree of deoxygenation are discussed.—G.F.

Internal cathodic protection. 4. The long thin circular tube with internal insulating coating C. Plumpton and C. Wilson (*Corr. Prev.*, 1959, **6,** Oct., 49–52) The mathematical theory, with a statement of the problem, a solution for a single anode, and a solution for an infinite set of anodes, followed by an approximate solution and conclusions are given.—S.H.-S.

Preventing fretting corrosion H. P. Jost (*Engineering*, 1960, **189,** April 29, 574) A letter. The use of MoS_2 is considered.

Placing raw materials and [metal] equipment in plastic casings with a view to their storage R. Meyer (*Corros. Anticorros.*, 1960, **8,** Feb., 70–74) A method is described for providing cocoon protection, fine threads of plastic being ejected from a compressed-air gun and criss-crossed so as to form a protective fabric applicable to irregular surfaces, sometimes over a light framework. Various examples are given.—S.H.-S.

ANALYSIS

The application of an electrographic method in analytical chemistry W. Wawrzyczek (*Chemica Analit.*, 1959, **4,** (5–6), 831–902) The main innovation of the apparatus described is a weighted swinging anode. The effects of pressure and time on the generation of iron is described. The following are described, the detection of: cobalt with iron, nickel with iron, tin with iron, tin with nickel, nickel with cobalt, iron with nickel and cobalt, cobalt with tin, and the analysis of pyrrhotine and galenite.

Photometric analyses in the industrial laboratory W. Degenhard (*Mét. Corros-Ind.*, 1959, **34,** Nov., 451–453) The analytical work of three Elko II photometers, used for the control of numerous varieties of steel and of non-ferrous alloys in the chemical laboratory of Fürstlich-Hohenzollernsche Hüttenverwaltung, is discussed in an interview between the author and the laboratory's director, Dr Boltz.

Study and use of a thermobalance acting under pressure P. Bastien and M. Colombié (*Mét. Corros-Ind.*, 1959, **34,** Nov., 447–450) The construction and operation of a gravity thermobalance are described.—S.H.-S.

Vacuum fusion provides quick analysis of metals V. S. McMullen (*Iron Steel Eng.*, 1960, **37,** March, 137) General principles are reviewed briefly.

Process for simultaneously sampling metals for spectrographic and chemical analysis W. R. Kennedy and R. N. Smith (*Appl. Spectrosc.*, 1960, **14,** (2), 53–54) A mould for the very rapid chilling of cast iron in particular, giving a consistent metallographic structure, is described.

Development of apparatus and methods for chemical and electrochemical spot testing, high manganese steels N.Y. Naval Shipyard (*PB* 139493, 1958, June, pp.7; from *US Govt. Res. Rep.*, 1959, **32,** Sept. 11, 368) (No abstract).

Determination of hydrogen and its practical application to melting practice A. Schöberl and H. Zitter (*Radex Rund.*, 1960, (1), 39–51) A suitable sampling method for the determination of H_2 content during melting is described; a divided Cu mould was used, and the method is simple and reproducible. Its use in the control of H_2 content in the basic electric arc furnace is described, and measures to reduce H_2 content in the steel are discussed (14 refs).

Estimation of hydrogen in pickled steel by vacuum extraction at 700 C K. Sachs and M. Odgers (*JISI*, 1960, **196,** Dec., 406–414) [This issue].

A micro gas chromatograph N. Sasaki, K. Tominaga, and M. Aoyagi (*Nature*, 1960, **186,** April 23, 309–310) A letter. A microdetector with a sensitivity of 10^{-10} mole/cc has been developed.

The determination of hydrogen in steel by the carrier gas method K. Abresch, W. Dobner, and H. Lemm (*Arch. Eisenh.*, 1960, **31,** June, 351–354) A new apparatus is described by which a high throughput of samples is possible, and which is simple to service. Diffusible H_2 is evolved at 1 200°C, and total H_2 determined in a sample melted in the high-frequency furnace.

Low pressure method for carbon analysis in steels: a note V. Ramakrishna (*Anal. Chim. Acta*, 1960, **22,** June, 592–594) In applying a low pressure method for the determination of less than 0·1%C in steels some difficulty was experienced. When the multiple coil trap for freezing out CO_2 was immersed in liquid air, O_2 from the gas stream condensed in it. Owing to this and the lowering of pressure it was difficult to maintain a steady outflow of gas from the trap and prevent a back suction of atmospheric air. The liquified O_2 in the trap tended to rise with the gas stream resulting in quick evaporation involving the risk of damage to the apparatus. This article describes a method of avoiding these difficulties.

Rapid determination of iron and manganese I. Sajó (*Koh. Lapok*, 1959, **14,** Nov., 525–526) A volumetric method of rapid determination of Fe and Mn in silicates, ores, rocks, slags, refractories, and metals using EDTA is described.—P.K.

Analytical applications of the Chelones. XXIV. Direct volumetric microdetermination of iron with EGTA using sulphosalicylic acid as end-point indicator F. Bermejo Martinez and M. Paz Castro (*Anal. Real. Soc. Espan. Fis. Quim.*, 1960, 56(B), Jan., 25–26) A new method for the direct titration of ferric iron on a microscale is proposed. The error, in 20 determinations, was found to average less than 0·1%.

Contribution to the determination of small amounts of boron in steel A. J. Leeb and F. Hecht (*Radex Rund.*, 1960, (1), 62–66) The method described is suitable for the determination of small amounts of B in plain C and alloy steels, and depends on the separation of B as methyl borate and photometric measurement of the boric acid–dianthrimide complex.

The accurate determination of cobalt A. G. Foster and W. J. Williams (*Anal. Chim. Acta*, 1960, **22,** June, 538–546) A number of primary standards for use on Co analysis have been compared under controlled conditions using the phosphate method of analysis. $[Co(NH_3)_6]Cl_3$, $[Co(NH_3)_5Cl]Cl_2$, and $K_3[Co(CN)_6]$ are recommended in preference to others which have hitherto been used.

Analytical applications of the chelones. XXV. Volumetric microdetermination of manganese with EFTA using eriochrome T black as end point indicator F. Bermejo Martinez and M. Paz Castro (*Anal. Real. Soc. Espan. Fis. Quim.*, 1960, 56(B), Jan., 27–30) A new method for the direct titration of Mn on a microscale is proposed. A high degree of accuracy is shown from 31 determinations.—P.S.

Polarographic determination of manganese H. A. Catherino and L. Meites (*Anal. Chim. Acta*, 1960, **23,** July, 57–65) In presence of Fe and other elements Mn can be determined rapidly, specifically, and accurately.

The complexometric determination of molyb-

denum J. B. Headridge (*Analyst*, 1960, **85**, May, 379–381) EDTA is used with molybdate. In the presence of ions other than alkali or alkaline earth metals modifications will be needed.

Use of deuterium as a tracer element for hydrogen in steel G. R. Fitterer, J. G. Bassett, and R. C. McCoy (*AIMME Proc. OH Comm.*, 1959, **42**, 61–70) The authors submit data from regular production heats of acid OH steel which show that the H_2 content is normally low during the refining period. They also show that, by O_2 lancing with the fuel turned off, the H_2 content can be reduced to very low levels of about 1 ppm. During tapping and teeming the content increases, and the authors suggest the use of deuterium to trace the source of this pick-up. Laboratory experiments indicating the feasibility of this method are described.—G.F.

Determination of gases in metals (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 13) A wide range of alloy steels was accurately analysed for H_2 down to 0·000005%. A description of the vacuum fusion apparatus used and its operation is given.

Rapid extraction of iron (III) with 2-thenoyltrifluoroacetone: direct colorimetric determination in the organic phase S. M. Khopkar and A. K. De (*Anal. Chim. Acta*, 1960, **22**, March, 223–228).

Determination of iron and iron aluminium mixtures by titration with EDTA D. G. Davis and W. R. Jacobsen (*Anal. Chem.*, 1960, **32**, Feb., 215–217) Sulphosalicylic acid is used as indicator.

Determination of micro-quantities of boron in steel by a solvent extraction method L. Pasztor, J. D. Bode, and O. Fernando (*Anal. Chem.*, 1960, **32**, Feb., 277–281) Ethylene dichloride is used and a complex with methylene blue is extracted and measured spectrophotometrically.

Complexometric estimation of micro amounts of cobalt using (ethylenedinitrilo)tetra-acetic acid R. N. S. Sarma (*Anal. Chem.*, 1960, **32**, May, 717–719).

Determination of cobalt as selenite V. D. Anand and G. S. Deshmukh (*J. Sci. Ind. Res.*, 1960, **19B**, March, 103–105) The $CoSeO_3$, $2H_2O$ can be directly weighed.

Determination of niobium in the presence of tantalum after extraction with methyl isobutyl ketone P. Senise and L. Sant' Agostino (*Anal. Chim. Acta*, 1960, **22**, March, 296–297) Direct spectrophotometric determination with phenylfluorone is described.

Determination of trace amounts of vanadium by means of a colour reaction with benzohydroxamic acid H. Waledziak, K. Gorczynska and D. Ciecierska-Stoklosa (*Chem. Anal.* 1959, **4**, (5–6), 883–890) The method depends on the colour reaction which V gives with benzohydroxamic acid. The choice of physical conditions for the analysis are described. The effect of quantity of reagent on absorption is given as well as the effect of the presence of Ag, Pb, Pt, Mn, Ni, Zr, Al, Ti, and Fe ions. The method serves for the determination of V in the range 20 to 100 mg/25 ml.

Determination of aluminium in precipitation-hardening stainless steel and high temperature alloys L. A. Machlan, J. L. Hague, and E. J. Meros (*NBSJ. Res.*, 1960, **64A**, March–April, 181–184) Oxine is used in presence of citrate and cyanide, the precipitate is fused under oxalate, dissolved, and reprecipitated with 8-hydroxyquinoline and weighed.

The determination of tin in pig iron and steel C. Mahr and K. Waffenschmidt (*Arch. Eisenhüt.*, 1960, **31**, April, 221–225) There is no generally suitable method; the procedure must be adapted to the composition of the material. Five cases are considered and recommendations made (13 refs).

The determination of trace elements in cast iron R. C. Rooney (*BCIRA J. Res. Dev.*, 1960, **8**, March, 193–199) The presence of very small amounts of various elements has been shown to have marked effects on the structure and physical properties of cast iron. To enable these effects to be studied, improved methods of analysis have been developed. The more successful techniques are described and their application to various elements outlined.

Contribution to the spectrochemical micro-analysis of oxide inclusions isolated from steel K.-F. Lüdemann, H.-W. Fenzke, and F. Gruner (*Neue Hütte*, 1960, **5**, April, 238–244) Details are given of the conditions of spark excitation, selection of line pairs, calibration, and evaluation of results. The method is suitable for the analysis of 0·5–1·0 mg material (23 refs).

Some elements of the technique of spectrography by X-ray fluorescence R. Diament, M. Mariée, H. Bizouard, and G. Pomey (*Mét. Corros.-Ind.*, 1959, **34**, Dec., 475–484) A review comprising the method of measurement used with corrections for dead time; some factors in the analysis of steels; size of samples, state of surfaces, preparation of samples; metallographic structure; first results in the analysis of iron minerals; production and control of 'powder-pastilles', and their control by X-fluorescence with notes on equipment.

'Replacement absorption coefficients'. Method in spectrophotometric analysis of binary mixtures. I. Application for determining traces of metals by means of colour reactions D. Ciecierska-Stoklosa, K. Gorczyinska, J. Swietoslawska, and H. Waledziak (*Chemia Analit.*, 1959, **4**, (5–6), 803–807) The method described is to be used for determining traces of two metals and is based on colour reactions. The principle is that instead of the absorption coefficients, 'replacement coefficients' are used which represent differences of absorption coefficients. The method is suggested for cases where normal methods cannot be used. So far the method has been used for determining traces of V and Fe.

'Replacement of absorption coefficient'. Method in spectrophotometric analysis of binary mixtures. II. Determination of trace amounts of vanadium and iron by the colour reaction with benzohydroxamic acid K. Gorczyinska, H. Waledziak, and D. Ciecierska-Stoklosa (*Chemia Analit.*, 1959, **4**, (5–6), 803–818) In this article the authors give a detailed description of the method as applied to the determination of traces of V and Fe. The equations used are given as well as the determination of standard solutions and finally the actual determination of V and Fe. Preliminary separation was not used. The method is inaccurate—the error being 15%.

Spectrophotometric determination of cobalt and nickel with oxamidoxime G. A. Pearse jun. and R. T. Pflaum (*Anal. Chem.*, 1960, **32**, Feb., 213–215).

Spectrographic determination of tantalum and niobium in 18/8 type stainless steels M. Neuilly (*Rev. Mét. Mém. Sci.*, 1959, **56**, Oct., 484–489) A Feussner spark source and a medium-dispersion instrument are used. Line-pairs were used and results obtained are reported. Ta and Nb are first separated chemically.

Spectrophotometric determination of vanadium as tungstovanadic acid G. W. Wallace and M. G. Mellon (*Anal. Chem.*, 1960, **32**, Feb., 204–207).

The use of radioisotopes in the research of metallurgical processes in steel works G. H. Pröpstl (*Stahl Eisen*, 1960, **80** June 23, 863–877) A lecture delivered to the Verein Deutscher Eisenhüttenleute dealing with the whole field of application of radioisotopes in steel works. This review is well illustrated and supplemented by 119 references and followed by a discussion.—T.G.

Determination of small contents of oxygen in gases by a continuous optical method J. Milewski (*Chemia Analit.* 1960, **5**, (1), 223–137) A method was worked out which is based on the measurement of the light absorbed by the mist formed when oxygen, from the analysed gas sample reacts with phosphorus. The apparatus measures oxygen in the 0 to 1% range. Gases containing more than 0·15% O_2 have to be diluted with an inert gas. A description of the apparatus and the electrical circuit as well as a calibration method are given.

Evaluation of laboratory methods for analysis of heavy metals in water R. C. Kroner D. G. Ballinger, and H. D. Kramer (*J. Amer. Water Works Assoc.*, 1960, **52**, Jan., 117–124) Cr, Cu, Fe, Pb, Mn, and Zn can be determined satisfactorily by current methods. Methods for Al and Cd require improvement.

The determination of calcium in the presence of iron and aluminium in industrial analysis K. Kapitaneczyk and Z. Kurzawa (*Chemia Analit.*, 1960, **5**, (1), 61–64) The method described is based on the fact that with iron and Al present there is precipitation of Ca oxalate even at pH values of 2·8 to 3·0. At a pH corresponding to the beginning of Fe $(OH)_3$ precipitation all the $Ca(OOC)_2$ is precipitated. The oxalate is then filtered off and determined manganometrically. The method is rapid and accurate. So far it has been used to determine Ca in sands, clays, limestone, and dolomite.

Rapid determination of vanadium I. Sajó (*Koh. Lapok.*, 1959, **1**, Aug., 383–384) A colorimetric method of rapid determination of V in ores, silicates, rocks, slags, and metals with diphenylcarbazone is presented. Its accuracy is +0·005%.—P.K.

Studies on analytical methods for trace elements in metals using radioactive isotopes. III. Determination of tantalum by the isotope dilution method. IV. Estimations of aluminium in steel using ^{45}Ca R type cation exchange resin H. Amano (*Nippon Kinzoku*, 1959, **23**, April, 222–225; 225–228) III. Accurate results for Ta in steel in the presence of Nb are obtained by using ^{185}Ta. A Ta tannin ppt is separated and the activity of Ta_2O_5 determined. If Ta/Nb < 1/100, repptn. is necessary (12 refs). IV. The sample soln. containing Al^{3+} at pH 3·0–4·0 is treated with a Ca–R type resin labelled with ^{45}Ca. The activity of eluted Ca is proportional to the Al present. Fe^{2+}, Mg, and NH_4 do not interfere seriously. The results agree with photometric determinations.

Rapid determination of calcium and magnesium I. Sajó (*Koh. Lapok*, 1959, **14**, Aug., 384–385) A volumetric method of rapid determination of Ca and Mg in silicates, ores, rocks, slags, refractories, and metals using EDTA is described.—P.K.

Rapid separation and gravimetric determination of aluminium in ferrous metals L. A. Keyser and C. D. Houston (*WADC Techn. Note* 58–361; *AD*–216495; *PB* 161003, 1959, May, pp.12; from *US Govt. Res. Rep.*, 1959, **32**, Nov. 13, 571) A rapid method of separating iron and Al has been developed with the Al being determined gravimetrically, and it is applicable to determining Al in ferrous metals in the absence of Ni. The separation is by the NaOH method and the Al is precipitated with 8-hydroxyquinoline.—S.R.-S.

Determination of the sulphate content of chromium plating solutions by a combustion method R. St J. Emery (*Electropl. Met. Fin.*, 1960, **13**, July, 253–257, 261) Reduction by Fe–Sn and EtOH followed by combustion to SO_2 is used.

Two years' application of spectrographic analysis in an iron- and steelworks laboratory J. Massinon and A. Daniels (*Rev. Mét.*, 1960, **57**, March, 239–246) A report on progress made with, and results obtained from the use of two high-dispersion recording spectrographs fitted with a profiling slit, installed at S.A. des Forges de la Providence at Marchienne-au-Pont. Results obtained in the analysis of basic Bessemer iron and steel, and electric steels are reported.

The influence of the mode of combination of an element on its determination by emission spectrographic analysis P. Dickens and A. Bähr (*Arch. Eisenh.*, 1960, **31**, March, 135–143) The non-ferrous example used in the investigation was Al, in the two forms of Al–Cu alloy and Al_2O_3. Excitation behaviour was examined (21 refs).

Spectrophotometric determination of phosphorus in iron and steel by extraction of phosphovanadomolybdate with methyl isobutyl ketone H. Kitagawa and N. Shibata (*Nippon Kinzoku*, 1959, **23**, April, 215–219) The optimum conditions for the determination are described; these result in the elimination of interfering elements (13 refs).—K.E.J.

Mutual influences in solution spectrography of the elements Fe, Ni, Cr and Ti taken in pairs G. Baudin and G. Hénon (*Compt. Rend.*, 1960, **250**, Feb. 22, 1463–1465) The 'third element effect' is discussed, with particular reference to the possibility of the spectrographic analysis of stainless steels by a solution method.

Determination of major constituents in alloy steels by spectrographic solution methods C. A.

Waggoner (*Appl. Spectrosc.*, 1959, **13,** (2), 31–33) Fe, Cr, Ni, Mn, and Mo are determined using Co as internal standard. The method is intended for identification or for specification analysis, and is especially useful where sample dimensions vary.

Mutual influences in solution spectrography of the elements Fe, Ni, Cr and Ti taken three at a time G. Baudin and M. Vo-Dinh (*Compt. Rend.*, 1960, **250,** March 7, 1818–1820) The effects are shown to be additive.

Spectrographic determination of nickel with mercaptoacetic acid P. C. Christopher and H. W. Hamme (*Appl. Spectrosc.*, 1959, **13,** (1), 7–10) After separation with dimethylglyoxine, thioglycollic acid is used to develop the colour in the presence of Na citrate.

Spectrophotometric studies on the nature of iron complexes with pyridine and quinoline-carboxylic acids A. K. Majumdar and S. P. Bag (*Anal. Chim. Acta*, 1960, **22,** June, 549–553) The compositions of the ferrous iron complexes with α-picolinic, quinaldinic, and quinolinic acids have been reinvestigated. In presence of KCN, iron combines with these reagents in a ratio of 1:1; at pH 5·9, in absence of cyanide the metal-to-reagent ratio is 1:2. The instability constants of the complexes are given.

Fluorescence analysis using X-rays and its development in metallurgy in the United States M. G. Pomey (*Publ. GAMS*, 1959, July–Sept., 43–81) Characteristics of X-ray fluorescence, apparatus, methods, preparation of powders, measurement of intensity and uses, including the analysis of special steels, are outlined (after a visit to the US).

Rapid automatic analysis by X-ray fluorescence of mineral powders and solutions used in hydrometallurgy by l'Union Minière du Haut-Katanga A. Hans (*Chem. Anal.*, 1960, **42,** June, 282–286) Condition for Cu and Co determination are given.

The determination of arsenic in coal and coke S. R. Crook and S. Wald (*Fuel*, 1960, **39,** July, 313–322) A colorimetric method following dry oxidation is described.

A rapid method of determining calcium and magnesium contents in slags of blast and steel-making furnaces using EDTA S. Kitahara, S. Hara, and K. Watanabe (*Rep. Sci. Res. Inst.*, 1956, **32,** July, 119–124).

The rapid determination of silica in refractories and minerals C. B. Belcher and L. B. Skelton (*Anal. Chim. Acta*, 1960, **22,** June, 567–570) This article describes a method for the rapid analysis of silica in minerals and refractory materials. After extracting the substance by sintering with powdered Na_2O_2 at 500° in Pt crucibles the silica is determined colorimetrically.

INDUSTRIAL APPLICATIONS AND USES

A commentary on the new British Standard 449 (1959): The use of structural steel in building (*Struct. Eng.*, 1960, **38,** June, 200–205) The discussion of the paper by J. Mason, with a reply by the author.

A note on IS: 800-1956. Indian standard code of practice for use on structural steel in general building construction T. V. Joseph and D. A. Simha (*J. Inst. Eng. (India)*, 1959, **39,** Jan., Part II, 449–465) The provisions of the specification are set out and discussed in some detail.

Discussions on a note on IS: 800-1956. Indian standard code of practice for use of structural steel in general building construction T. V. Joseph, D. A. Simha, and K. S. Rangasami (*J. Inst. Eng. (India)*, 1959, **39,** Aug., 1206–1208) A written contribution with reply. The source of the limits prescribed is asked for and indicated.

Heavy duty irons in process equipment F. G. Benz (*Eng. Min. J.*, 1960, **161,** March, 93–94) The properties of Meehanite, and its application to iron castings for crushers, rod and ball mills, etc., are described.

Comparison of shielding properties of iron and stainless steel in the ORNL lid tank (expt. 38) G. T. Chapman and J. D. Flynn (*CF-53-6-187*, 1957, April, pp.29; from *US Govt. Res. Rep.*, 1959, **31,** (1), 62) (No abstract).—S.H.-S.

Steels for the manufacture of automobile parts W. de Lima e Silva (*Eng. Min. e Met.*, 1959, **30,** Nov., 257–264) [In Portuguese] Standard specifications for automobile steels are proposed. The steels recommended, their heat-treatment and properties and their applications are listed and discussed.—P.S.

Properties of uranium dioxide–stainless steel dispersion fuel plates S. J. Paprocki (*BMI-1335*, 1959, April, pp.25; from *US Govt. Res. Rep.*, 1959, **32,** Sept. 11, 404) (No abstract).

Prestressed steel girder K. K. Banerjee (*J. Inst. Eng. (India)*, 1959, **40,** Dec., 286–314) Calculations associated with a suggestion for prestressing the girder as a whole are presented. The process should economize steel and strengthen existing structures. Tests on an open web girder prestressed with high-tensile wires are included.

Design of piping systems for high pressure and high temperature S. K. G. Hazra (*J. Inst. Eng. (India)*, 1960, **40,** Feb., Part 2, 219–230) Boiler systems are considered.

High-tensile alloy steel rails D. S. Kazarnovskii, M. A. Gershgorn, A. A. Sorokin, A. D. Kutsenko, M. T. Bul'skii, F. F. Sviridenko, and I. P. Kravtsova (*Stal'*, 1960, (5), 458–465) Rails made from experimental melts were examined to arrive at an alloy steel with suitable properties. Rails with 0·63–0·75%C and 0·5–1·0%Cr can be used without annealing. Satisfactory production of rails with 0·32–0·42%C and 1·7–2·4%Cr has not yet been achieved.

Thin walled stainless tubes carry gas to cool generators Allis-Chalmers Mgf. Co. (*Steel*, 1960, **146,** March 28, 86–87) The incorporation of rectangular-section stainless-steel tubes in the stator coils of steam turbine generators is explained. Thermal and electrical properties are suitable. The coils carry hydrogen for cooling.—D.L.C.P.

Ferrous metals in the automobile industry J. Pomey (*Met. Ital.*, 1960, **52,** March, 49–61) New developments in ferrous metals used in the automobile industry are due not to new alloys but to progress in smelting, forming, and heat-treating cast iron and steels, which help to lower alloy consumption and costs. Many examples are given of the methods of heat and chemical diffusion treatments, hardening, and prestressing, which improve performance, and stress resistance.

Steels for the machine industry E. Orosco (*Geol. e Met.*, 1959, **20,** 93–109) A review of the steel industry in Brazil, covering factors of expansion, machine tool production, the Brazilian steel market, conditions of market supply, and an approximation between consumption and production, with statistical tables.—S.H.-S.

On the production of steel for roller bearings J. Duda (*Hutn. Listy*, 1960, **15,** (1), 20–25) The principal metallurgical problem is the attainment of a steel with low non-metallic impurities in the form of inclusions. A statistical analysis of the nature and quantity of impurities in works melts, with samples taken over two years, showed that the decarburization rate and the burning off of C influence the amount of inclusions significantly. The length of the reduction period, and the time of the FeCr addition were not found to have any effect. Various other significant factors are listed. The observation should facilitate the production of better steel in basic arc-furnaces.

Bars of only an inch in diameter will be able to be used instead of huge iron beams (*Eng. Min. e Met.*, 1959, **30,** Sept., 155–156) [In Portuguese] Greatly improved strength is forecast as the result of basic research on dislocations and metal whiskers.—P.S.

Nickel steel for low temperature applications (*Machinery*, 1960, **96,** Jan. 27, 183) Low-carbon wrought and cast steel containing 9%Ni possesses outstandingly good mechanical properties at low temp. and is widely used for equipment for handling liquid gases, particularly oxygen. The most common form used is ASTMA 353. Correct methods of heat treatment and welding are described, and the other advantages of this type of steel are summarized.

Metals for the atomic industry—the metallurgy of atomic metals (*Mét. Constr. Mécan.*, 1959, **91,** Oct., 707, 708, 711, 713, 714, 715) A report on papers given at the metallurgy symposium organized at Saclay by the Institut National des Sciences et Techniques Nucléaires and dealing particularly with research on crystalline structure.

HISTORICAL

Metallographic examination of some Etruscan steel sword blades C. Panseri, C. Garino, and M. Leoni (*Documenti e contributi per la Storia della Metallurgia*, preprint, pp.33) This study gives valuable and accurate information on the technique of manufacture. A detailed description with photographs illustrates the historical origin of these relics.

Ancient metallurgical furnaces in Great Britain to the end of the Roman occupation T. K. Penniman, I. M. Allen, and A. Wootton (*Sibrium*, 1958–1959, **4,** 97–127, reprint) [In English] Brief accounts of all identified furnaces in Great Britain, not including other evidences of smelting operations.

A bloomery hearth experiment and the forging of the puddled balls J. W. Gilles (*Stahl Eisen*, 1960, **80,** July 7, 943–949) A puddling furnace was constructed and used for two runs which were quite successful, it was however rather difficult to forge the puddled balls or sponge. The trials are described in detail (17 refs).—T.G.

The History of Rasselstein C. Peters (*Stahl Eisen*, 1960, **80,** July 7, 971–972) The history of the Bandstahlwerk Andernach as it is known today is briefly presented, beginning with its origin in a flour-mill erected by the Graf zu Weid in 1647.

The Lloyds in the early English iron industry M. W. Flinn (*Business History*, 1959, **11,** Dec., 21–31, reprint) The period covered is 1699–1727, with ironworks in Birmingham and Dolobran near Welshpool, with family history before and after these dates.

Sir Ambrose Crowley and the South Sea Scheme of 1711 M. W. Flinn (*Journal of Economic History*, 1960, March, 51–66, reprint) Sale of iron to the navy from the ironworks at Gateshead was the occasion of the transactions here described.

Cecil Henry Desch 1874–1958 (Sir) A. McCance (*Biographical Memoirs of Fellows of the Royal Society*, 1960, **5,** Feb., 49–68, reprint)

Stainless-steel jubilee: Further extensions to Firth-Vickers Works C. Sykes (*Iron Coal Trades Rev.*, 1960, **180,** April 22, 929–930) An address, giving briefly the history of the company.

Japanese steel production G. Grenier (*Mines Mét.*, 1960, May, 277–279) The history of Japanese steel production since the opening of the first foundry at Yawata in 1880, and its development as the fruits of the Chinese indemnity following the war of 1894–1895, is traced down to the present day, with a survey and summary of current Japanese producers left intact by the second World War.—S.H.-S.

On the technique employed by the Etruscans for manufacturing iron weapons. The metallographic examination of an iron battleaxe of the 6–7 century A.D. from Vetulonia C. Panseri and M. Leoni (*Met. Ital.*, 1960, **52,** May, 229–236) The test proved that this weapon was made by the Etruscan welded damascene technique. This consisted of superimposing and hammer-welding steel of varying carbon contents which produced weapons of high hardness and impact strength. This axe had undergone a martensitic hardening process on the cutting edge in contrast with other iron weapons which showed a crude forging structure.

Methods of making chain mail (14th to 18th Centuries). A metallographic note C. S. Smith (*Technology and Culture*, 1959, **1,** Winter, 60–67, reprint) Cross-sections of rivets and links are shown and methods of fabrication are considered.

British smelting from 1870 to 1914. I. Blast furnaces G. Grenier (*Echo Mines Mét.*, 1960, **1,** 19–21) A review in general terms with a list of improvements and their inventors.—S.H.-S.

Twenty-five years of stainless steel C. Sykes (*Iron Steel*, 1960, **33,** May, 189–190) A report of the speech made by the chairman of Firth-Vickers Stainless Steels on the occasion of the Company's jubilee. The growth of the company and its present equipment are described.

Percy Carlisle Gilchrist E. N. Simons (*Brit. Steel*, 1960, **26,** April, 114–115) An assessment of the part played by Gilchrist in association with Thomas in the development of the basic Bessemer process.

ECONOMICS AND STATISTICS

The iron and steel industry in Europe, 1958–1959 (*Trends in Economic Sectors*, 1960, **6,** May, pp.185) A study prepared by the Iron and Steel Committee of OEEC.

The Iron and Steel Industry A. Giménez Sanmartín (*Dyna*, 1960, **35,** April, 250–285) [In Spanish] A world review of the industry is provided and in the first part data on programming, planning, and modernization during 1959 are supplied, taking each country or region in order. The latter part provides information on the productivity of the North-American, English, Russian, and Japanese iron and steel industries by means of translated extracts of reports published elsewhere.—P.S.

Long-term trends of the Iron and Steel Industry of the World: A study by the Economic Commission for Europe (*Glückauf*, 1960, **96,** July 2, 886–888) This is a summary—notably from the German point of view—of a United Nations publication 'Long-term trends and problems of the European Steel Industry' prepared by the Secretariat of the Economic Commission for Europe (Geneva, 1959).—T.G.

The Japanese iron and steel industry G. Grenier (*Min. Mét.*, 1960, June, 353–354) Statistical, with map.

The competitive position of Lake Superior iron ores Part II J. S. Wilbur (*Blast Furn. Steel Plant*, 1960, **48,** April, 365–370) Economic problems connected with development of competitive ore deposits and transportation costs are discussed.

Brazilian iron ore for Japan O. Rangel (*Eng. Min. e Met.*, 1960, **31,** Feb., 73–80) [In Portuguese] Details of Itabira ore exported to Japan are supplied: 350000 t at an average price, FOB Vitória, of US$11.00 were exported in 1959. A full account of the Japanese industry is given with details of iron and steel production. The type, quantity, and cost of Japanese iron ore imports are described (18 refs).—P.S.

The correct steel at the right place W. Kuntscher (*Technik*, 1960, **15,** July, 458–462) In order to facilitate the correct use of the steel qualities available in the German Democratic Republic a Socialistic Steel Advisory Centre has been formed. This was found necessary as in the socialistic economy no advertisements are used for promoting any special products.

The steel industry metals (*Min. J.*, 1960, May, Annual Review No., 31–46). **Iron and Steel** J. H. Thompson (31–46). **Manganese** S. Bracewell (33, 35). **Nickel** A. G. Thomson (35, 37). **Cobalt**. (37, 39). **Chromium** (39, 41). **Tungsten** (41). **Molybdenum** (41, 43). **Vanadium** (43, 45). **Niobium and Tantalum** J. Sandor (45–46) Brief technical notes and statistics.

Organisation of cyclic production in metallurgical plants (review of a book by L. M. Liberman) I. A. Medvedev and E. S. Glickman (*Stal'*, 1960, (6), 560–561).

The development of a steel industry—factors affecting the economics of steel M. D. J. Brisby (*NML Tech. J.*, 1960, **2,** Feb., 35–46) A review of world statistics and requirements for setting up a steel industry; siting and economics of optimum size modern plants, layouts, and capital investment needs, together with expected returns are considered.—S.H.-S.

An explosive period for metals C. L. Kobrin (*Iron Age*, 1959, **184,** Oct. 22, 177–179) The effect of recent technological developments on the future use of various ferrous and nonferrous metals is discussed.—A.G.

Effect of reorganization on efficiency D. M. Potter (*Iron Steel*, 1960, **33,** May, 202–206) The effects of plant changesi n the various sections of Steel Peech and Tozer's works between 1945 and 1951 on their efficiency are described.

Review of the Italian Iron and Steel Industry in the post-war period: its development and prospects in the immediate future [ASSIDER] (*Met. Ital.*, 1960, **52,** May, 203–213) This paper describes the structural problems of the industry in the post-war period with particular regard to the raw material situation and location. Relevant production statistics are given. The structure and development of the individual steel companies is described together with a review of the latest technical developments.

Technical progress and steel economy S. Kaviński (*Prz. Techn.*, 1960, **81,** (14), 4–6) In the production of pig iron and steel, Poland depends to a large extent on the import of foreign ores. Consequently the author suggests that the strength of construction steel St.52 used in civil engineering should be increased, thus bringing about a saving in weight of 15–20%. Losses in transformer plates which are at 1·3 W/kg should be reduced giving a considerable annual saving in capital investment and energy. Lastly an increase in the manufacturing capacity of reinforced concrete pipes, for drainage and water supplies, should be made. This would lead to a weight saving of 80–90%.

Are the present-day prices of iron and steel correct? E. Schmidt (*Neue Hütte*, 1960, **5,** April, 245–251) Refers to East German conditions.

Post-war Hungary (*Met. Bull.*, 1960, May 7, i–iv, 21) Statistical, with a section on iron and steel and a map.

Iron metallurgy F. Szlajmer (*Prz. Techn.*, 1960, **81,** (1), 26–28) The author gives a summary of statistical data concerning the Yugoslav iron and steel industry in 1939 and the years 1953–1958. Mention of specific works is made with production capacity in treating iron ore, scrap, steel, and specialized products. The information indicates very considerable development in recent years.

Expansion of the iron and steel industry in Brazil E. de Macedo Soares e Silva (*Geol. e Met.*, 1959, **20,** 5–16) An historical review, covering the static condition of Brazilian steel consumption of 150000 to 250000 t (mostly imported) between 1901–1930, and the growth since 1930, of a native industry, rising to 1700000 t in 1959, and with a forecast of 3500000 t production for 1962.—S.H.-S.

Chinese steel and railway developments (*Rail Steel Topics*, 1960, **5,** (3), 37–45) This article reviews the achievements in these fields during the past decade and the enormous potential for growth which is likely to make China a major industrial power by the end of the 1960's. The main developing steelworks are described and also the rail networks.

The boiler making and sheet and plate industries (*Mét. Const. Méc.*, 1960, **92,** April, 205–211) A review of the size and importance of the sheet, plate, and boilermaking industries, compared with French industry as a whole, with the number of members, turnover, and a description of the organization and activities of the Syndicate National de la Chaudronnerie, de la Tôlerie et de la Tuyauterie Industrielle.—S.H.-S.

MISCELLANEOUS

New dimensions in metallurgy D. H. Wenny jun. (*Bell Lab. Record.*, 1960, **38,** April, 130–134) High purity materials, especially Supermalloy strip and Vibralloy are described.

Cylindrical helical springs with non-uniform pitch S. Gross (*Draht*, 1959, **10,** Aug., 358–363) It is shown mathematically that the properties of a spring with non-uniform pitch are a function not only of the wire length but at least to the same extent on the development of the spring.

A note on δ-Fe_2O_3 S. Okamoto and T. Takei (*Sci. Papers Inst. Phys. Chem. Res.*, 1959, **53,** Sept., 201–206) [In English] Observed diffraction patterns on δ-Fe_2O_3 can be adequately interpreted by assuming layer deficiencies in the plane perpendicular to the C-axis.

Hydrogen overvoltage and the reduction of Fe_3O_4 monocrystals in alkalis A. S. Afanas'ev and O. Ya. Miroshnichenko (*Ukrainsk. Khim. Zhurn.*, 1959, **25,** (3), 326–333) Before the start of the electrical reduction of H_2O, two processes take place in the monocrystal: the electrical reduction of O_2 and the gradual electrical reduction of the oxide. This latter process proceeds very slowly and the microcrystal is reduced only insignificantly. Together with the electrical decomposition of H_2O there also begins the intensive reduction of the oxide with evolution of H_2. The yield of reduced Fe decreases with an increase in current density.

Calcium iron silicate H. E. Swanson, I. M. Cook, T. Isaacs, and E. H. Evans (*NBS Circ.* 539, 1960, **9,** Feb., 25, 22–23) This is one of a compilation of standard X-ray diffraction powder patterns.

The amount of haemoglobin measured on smelting furnace labour Y. Norimatu, K. Takayanagi, M. Kiyonaga, and M. Ujioka (*J. Lab. Hyg.*, 1960, **9,** Feb., 10–13).

Possibilities of automation offered by electronics in the iron and steel industry B. Plettner (*Rev. Tech. Luxembourg*, 1960, **52,** April–June, 80–92) [In French] The writer reviews developments in the iron and steel industry with reference to the rate of electronic systems in improving the quality and flow of production. Transistors, systems for regulating speed, transmitting numerical and other information and instructions and electronic measuring and calculating machines are dealt with.

Solubility of iron–nickel alloys in liquid lead —700 to 100 C+ B. Fleischer and J. F. Elliott (*NYO*–4684, 1958, pp.22; from *US Govt. Res. Rep.*, 1959, **31** Feb. 13, 114) (No abstract).—S.H.-S.

Phase equilibria in the system La_2O_3–iron oxide in air V. L. Moruzzi and M. W. Shafer (*J. Amer. Ceram. Soc.*, 1960, **43,** July, 367–372)

Investigation of various metal protective coatings on the gum formation and oxidation stability of gasoline V. O. Hatch (*AD*–137784; *PB* 131738, 1957, July, pp.36; from *US Govt. Res. Rep.*, 1959, **31,** Jan. 16, 42) Effects of coating materials on petrol gum formation and oxidation stability were investigated, also corrosion protection afforded by the coatings to steel. Forty-six coatings, including five commercial coatings were evaluated, and tabulated data are presented for a great many tests.—S.H.-S.

Symposium, technology of molybdenum and its alloys: held at Rackham Memorial Building, Engng. Soc. of Detroit (*ONR ACR*–12; *PB* 131793, 1956, Sept., pp.21; from *US Govt. Res. Rep.*, 1959, **31,** Jan. 16, 41) Contains abstracts of papers delivered at this symposium: Mo as structural material, preparation and fabrication of Mo and its alloys, European developments of Mo, metallurgy of Mo and Mo-base alloys, and Mo alloys for gas turbine applications.—S.H.-S.

BOOK NOTICES

AMERICAN WELDING SOCIETY. '*Soldering Manual*', 9×6 in, pp.ix+170. Illustrated. 1959, New York: The Society.

The A.W.S. defines soldering as a joining process by heating below about 800°F and using a non-ferrous filler metal distributed by capillary action with a melting point below that of the base metal. The temperature range differentiates soldering from brazing which is treated in the companion *Brazing Manual*. The metals to be joined dictate to a great extent the flux, solder, and heating methods that are to be used. This book is arranged with this in mind, and logically and with precision it provides an excellent up-to-date guide to an old art.

BARNABA, T. '*Fabricazione dell'acciaio*'. 10×7 in, pp.xxvii+473. Illustrated. 1960, Milan: Editore Ulrico Hoepli. (Price L.4000.)

The author, a member of the Ilva blast-furnace and steelworks, has intended this book for the training of technicians and as a reference book for them. It certainly achieves its objective of reviewing the various fields of knowledge necessary to technical workers in steelworks. It is an extremely useful textbook of its kind but probably the best use to which it could be put in this country is as a reference book for translators working in Italian. The book which has a good index describes operations from charging to teeming, beginning with an historical introduction and concluding with a review of steel properties. There is also a fairly full description of casting pit techniques. The description starts with the basic open-hearth

process and includes the acid open-hearth, Bessemer, basic Bessemer, oxygen top-blowing, oxygen open-hearth, electric duplex and triplex processes and also special systems such as the Perrin, Bertrand-Thiel, and Talbot processes. This section is followed by a discussion of the fundamentals of the physical chemistry of steelmaking. The descriptions are straightforward. Reference is made to such items as flame luminosity, fuel consumption, and refractories, but not to such subjects as the aerodynamic phenomena related to furnaces. There is a separate chapter on rimming and killed steels. Much useful information is given in the form of histories of actual heats. In the theoretical sectio the author starts with the first principles of physics and chemistry, discusses various slag–metal reactions, the theory of heat treatment, and the structural components of steel.—R. SEWELL.

BOOTH, A. D. (Editor). '*Progress in Automation*'. Vol.I. 8½×5¾ in., pp.viii+231. Illustrated. 1960, London: Butterworths Scientific Publications. (Price £2 2*s*.)

This first volume in a new series contains 11 papers all of wide interest. The book is divided into three main sections: an introduction which gives a brief history of the subject and provides some definitions of useful terms, a discussion of some of the fundamental techniques, and a description of a number of applications. Of most interest to the iron and steel industry is a short paper by G. Syke (abstracted in *JISI*) on automatic control in the manufacture of steel strip. It is a useful summary of well-known developments but unlike some of the other contributions it is without a list of references.

BRITISH STEEL CASTINGS RESEARCH ASSOCIATION. '*Data Sheets on Dust Collectors*'. 10×8 in., pp.ix+39. Illustrated. 1960, Sheffield: The Association. (Price £1 10*s*.)

First published in May 1958, in an edition restricted to members of BSCRA, these data sheets have now been revised and made generally available. Details are given of 32 dust collectors primarily suited to steel foundry applications.

CABLE, J. W. '*Vacuum Processes in Metal-working*'. 7½×5 in., pp.202. Illustrated. 1960, New York, London: Reinhold Publishing Corp., Chapman & Hall Ltd. (Price £2 4*s*.)

The preface suggests that this volume should be a valuable introduction to the subject of vacuum metallurgy, being of a practical rather than a theoretical nature. This view is confirmed in the opening chapters, where some lucid and entertaining descriptions of the principles of vacuum technology are given. In the later chapters, however, it is a little disappointing to find that the vacuum aspect is at times overshadowed by excessive descriptions of heating processes. Outgassing, refining, purification, and distillation are dealt with briefly but adequately, as are vacuum sintering, vacuum deposition, vacuum brazing, and welding. Vacuum melting and casting are treated in more detail, but it is unfortunate that vacuum degassing is included as a short digression in this chapter. Illustrations are few and unnumbered. One has the feeling that in an introductory work of this nature a few simple line diagrams adequately explained in the text would have been of more value. Equipped with a comprehensive index, the book is well worth reading provided it is understood that it is intended as an introduction and not a work of reference. The author recommends the reader to consult other works for technical details.

—G. HOYLE.

CLARKE, N. (Editor). '*A Physics Anthology*'. 8½×5½ in., pp.viii+323. 1960, London: Chapman & Hall Ltd. (Price £1 15*s*.)

An agreeable *pot-pourri* which has already appeared in the *Bulletin* of The Institute of Physics on whose behalf it is published. There are 23 contributions, all of value. There is no single theme although perhaps there is a bias towards the philosophy of science set by the first notable contribution from the President of the Royal Society and concluding with a discussion 'Ethics and the Scientist'.—M. L. PEARL.

CARPOVICH, E. A. '*Russian–English Metals and Machines Dictionary*'. 8×5½ in., pp.112. 1960, New York: Technical Dictionaries Co. ($9.00.)

This dictionary contains about 9000 Russian entries and it covers primarily metallurgy, metals and alloys, metalworking, and machines and machinery. Although many of the entries can also be found in more comprehensive dictionaries, such as L. I. Callaham's *Russian–English Technical and Chemical Dictionary*, this dictionary contains a considerable number of terms not given elsewhere. As far as ferrous metallurgy is concerned, published dictionaries available at present give but few English equivalents of the Russian names for parts of OH and other furnaces and of surface defects in ingots and their products. It is to be hoped that these and other similar terms will be included in a future edition or in some other publication. Until many more such terms have been translated, it seems somewhat wasteful to have so much overlapping in Russian–English dictionaries. In the meantime, this book can be recommended as an additional dictionary for translators concerned with metallurgy in view of the hitherto unpublished terms it includes. There are some printing or spelling mistakes but in spite of this the dictionary should still be of considerable value.

—C. I. PEDERSEN.

GRABBE, E. M. *et al.* '*Handbook of Automation, Computation and Control*'. Vol.2. Computers and Data Processing. 9×6 in., [31 chapters not continuously paginated]. 1959, New York, London: John Wiley & Sons Inc., Chapman & Hall Ltd. (Price £7.)

This second volume (the first on Control Fundamentals was reviewed in *JISI*, October 1959), deals very competently with six main sections, Computer Terminology, Digital Computer Programming, The Use of Digital Computers, Design of Digital Computers, Design and Application of Analogue Computers, and Unusual Computer Systems. Each chapter starts with definitions and descriptions and then goes on to more complicated theory, analysis, and applications. There are numerous literature references at the end of each chapter.

GROSSKINSKY, O. (Editor). '*Handbuch des Kokereiwesens*'. In 2 volumes. 9½×7 in., pp. xvi + 547, xii + 542. Illustrated. 1955, 1958; Düsseldorf: Dipl.-Ing. Karl Knapp Verlag. (Price: Vol. 1 DM. 76.—; Vol. 2 DM.86.—.)

The Germans are more book-minded than the English and already have the Handbuch der Kokerei published in two volumes in 1927–8 by Wilhelm Gluud, which was translated or used as a basis for editions in English (1932) and French (1937). Gluud's successor as Director of the Coal Research Institute, Dortmund, has in effect, brought the subject up-to-date as a handbook of coke-oven technology. Volume I deals with coal, coke-ovens, coke, and thermal balances and is a compilation by about 20 different contributors. Volume II extending to over 500 pages deals in 12 chapters with crude gas; recovery of ammonia and benzole; removal of sulphur, naphthalene, nitrogen oxides, and the drying of the gas; the practice of removal of tar, hydrogen sulphide, and the production of sulphate of ammonia and benzole; the recovery of cyanogen compounds, ammonia liquor, and phenol; tar distillation; other ammonia products; the recovery of aromatic hydrocarbons; the recovery of sulphur; the use of the purified gases for synthesis, etc.; the removal of benzole, naphthalene from the gas under moderate pressures; and cooling. As in Vol.I there are about 20 contributors. The volumes are therefore essentially reference books for which good indexes are essential; there are both author and subject indexes to each volume to aid such reference. There are 262 illustrations including many of the ingenious process-outlines in which the Germans are particularly competent, and 86 tables. All the illustrations are line-drawings within the text so that the book is compact. The type is Roman and easy to read and the book is well produced but expensive.

—R. A. MOTT.

LEMENT, B. S. '*Distortion in Tool Steels*'. 9×6 in., pp.v+173. Illustrated. 1959, Novelty (Ohio): American Society for Metals. (Price $10.00.)

This is an extremely valuable book for the practical man engaged in the heat treatment of tool steels, and aware of the pitfalls to be encountered by fine variations of the same heat treatment. The book explains how the dimensional changes occurring can be predicted and thus allowed for by designers. Since it is becoming common to design tool steel components with tolerances in the range of 10 to 100 micro-inches, economical manufacture requires knowledge of dimensional changes sufficient to facilitate choice of machining operations so that the final dimensions of a part will not change significantly during storage or under normal service conditions. The book discusses these and related topics and has chapters dealing with causes of distortion, measurement of dimensional changes, calculation of size changes, control of distortion, hardening, cold treating, tempering, and ageing. There is an index and the published work of numerous individuals cited in the references, as well as the author's own experience and research provides much of the data of the book; an attempt has been made to collect all important information available on dimensional changes in tool steels, and to present this data in convenient form. The book will serve as a useful concise reference work for those who would not normally have access to sufficient literature on this subject.—W. G. SALISBURY.

LOTHIAN, G. F. '*Absorption Spectrophotometry*'. 2nd ed. 8½×6 in., pp.viii+246. Illustrated. 1958, London: Hilger and Watts. (Price £2 12*s*.)

SANDELL, E. B. '*Colorimetric Determination of Traces of Metals*'. 3rd ed. 9½×6 in., pp.xxii+1032. 1958, London, New York: Interscience Publishers Ltd. (Price £9 5*s*.)

These are two completely revised editions of books already well known to the analytical chemist.

Lothian's book was first published in 1949; since that date absorption spectrophotometry has grown rapidly and it has become necessary to rewrite most of the chapters in line with present-day developments. Part I is concerned with the nature and laws of absorption and contains a useful comparative table in which American and British terminology is defined precisely. Of particular interest is an account of the effects of finite slit-width and diffusing media on the applicability of Beer's Law. Much useful practical advice is given in a chapter on accuracy in spectrophotometry. Some cautionary notes on differential spectrophotometry will be of especial value to workers interested in the colorimetric determination of major constituents in ferroalloys and alloy steel. Part II contains two chapters, one on the relationship between absorption spectra and the chemical structure of organic compounds, and the other illustrating a few typical examples of the application of absorption spectrophotometry in analysis. Part III consists of six chapters on technique. The principles of the design of photoelectric, thermal-detector, photographic and visual spectrophotometers are considered, and the author gives concise details of some representative commercial instruments. Absorption cells, solvents, and standards for checking spectrophotometers are dealt with in the final chapter.

Sandell's comprehensive manual of selected methods for trace metal analysis, first published in 1944, has been enlarged and brought up to date in this third edition. The general plan of treatment is identical with the earlier editions: Part I is concerned with general aspects and Part II is a collection of procedures for 48 metallic elements and the rare-earth group. A trace constituent is generally accepted as one occurring to the

extent of 0·01% or less but Sandell points out that methods used in trace analysis are often useful for constituents in the range 0·01–1%. Methods for the separation and isolation of elements are compared in Part I, and the properties of some 26 of the best known colorimetric reagents and their derivatives are discussed. Of particular note is a section on dithizone in which the author unravels the extensive literature on this reagent. The layout of Part II is excellent: each element has a section on separations, methods of determination and applications, and each section is neatly divided under appropriate sub-headings. The author has attempted to make a survey of all the literature on the separation and colorimetric determination of metal traces published in recent years. From this mass of material a relatively few methods are presented for each element and, wherever possible, the underlying principles of the determinations have been examined. A large amount of miscellaneous information is given in the form of footnotes and it is somewhat difficult to decide why the author has not chosen to incorporate such material in the text. In contrast with many American books of this nature, the author does not place too great an emphasis on American literature but has endeavoured to cast his net far and wide for work as recent as early 1957. References are given at the bottom of each page and, in addition, a number of addenda in the form of annotated literature references list important contributions published while the manuscript was in the hands of the publishers.

Together these two books provide the essence of the theory and practice of absorption spectrophotometry. Lothian's manual combines an excellent account of theory and principles with a survey of instrumentation and good deal of practical advice to the operator. Despite its high price, the American book is essential to trace analysis. Much of its contents is relevant to elements present in more normal concentrations and it would certainly prove of value to all laboratories concerned with the analysis of metals and alloys.—P. H. Scholes.

Metallurgical Society (of AIME) Conferences. Volume 5 edited by H. C. Gatos: '*Properties of Elemental and Compound Semiconductors*'. pp.xi + 340. (Price $8.50.) Volume 6 edited by E. W. Earhart and R. D. Hindson: '*Flat Rolled Products II: Semi-Finished and Finished*'. pp.ix + 150. (Price $4.00.) 9 × 6 in. Illustrated. 1960, New York, London: Interscience Publishers.

These latest publications of The Metallurgical Society of AIME maintain the high standard reached in earlier volumes (reviewed in *JISI*, August 1960). Volume 5 is the report of a conference on semiconductors held in Boston on 31 August–2 September 1959. It is divided into five parts: Metallurgical and Chemical Aspects; Solid State and Surface Reactions; Chemical and Lattice Defects; Physical Properties and Device Applications; and (a record of discussion) the Role of Dislocations in Device Applications. Volume 6 reports the proceedings of the Second Conference on flat rolled products, held at Chicago in January 1960. It contains eight papers each with discussion. The material is divided into two main sections dealing with processing to semi-finished and finished flat-rolled products.

Plénard, Elizabeth. '*Considérations sur le module d'élasticité et la capacité d'amortissement des fontes grises*'. 10½ × 8 in., pp.166 + 68. Illustrated. 1958, Paris: Centre Technique des Industries de la Fonderie. (Price Fr.2300.)

This is a thesis submitted for the degree of Ingénieur-docteur at the Sorbonne. It is a most able piece of work dealing with the elastic properties of grey iron, the measurement of its Young's modulus, and the influence of structure and method of manufacture on its elastic properties. It has been produced in duplicated form but the illustrations are clearly presented. An abstract of the thesis has appeared in *Journal d'Informations Techniques des Industries de la Fonderie*, January 1959, No.102, pp.13–16.

Putilova, I. N. *et al.* '*Metallic Corrosion Inhibitors*'. [Translation into English from the Russian.] pp.viii + 196. Illustrated. 1960, London: Pergamon Press. (Price £3 3*s*.)

This little book stems from the appreciation in Russia that as industry grows the problems of protecting metals from corrosion increase in importance. The use of higher temperatures, pressures, and dimensional accuracy has made the application of more effective means of protecting metals essential. The authors rightly claim that the use of corrosion inhibitors can make possible the preservation of millions of tons of metals, improve working conditions, and increase productivity. They had already reviewed the more limited field of the application of inhibitors of acid corrosion in 1948. Since then much new experience has been gained and more effective inhibitors have been introduced. They have therefore endeavoured in the first two chapters to systemitize and generalise the available information on the theory and practice of applying corrosion inhibitors. The other four chapters deal with the use of corrosion inhibitors in aqueous solutions of acids, aqueous solutions of alkalis, water and aqueous solutions of salts, atmospheric corrosion, and non-aqueous liquid media.

This translation has been printed by means of a photographic copying of the typist's sheets. More than one type has been used and the degree of reduction in the copying has not been uniform in filling the pages. The text is therefore less easy to read than print, but errors in setting up will have been avoided. At the ends of the introduction and of the six chapters there are a total of 332 references, which indicate the wide reading, by the authors, of foreign literature. The Russian references will be new to many corrosionists and they will be welcome.

—T. Henry Turner.

Smales, A. A., and Wager, L. R. (Editors). '*Methods in Geochemistry*'. 9 × 6 in., pp.vii + 464. Illustrated. 1960, New York, London: Interscience Publishers Ltd. (Price £4 14*s*.)

'The primary purpose of geochemistry is on the one hand to determine quantitatively the composition of the earth and its parts, and on the other to discover the laws which control the distribution of the individual elements . . .' The opening sentence of this book, which is a quotation by V. M. Goldschmidt, briefly describes the scope of geochemistry, a subject not of purely scientific interest only but with increasing economic applications, for example, in the search for mineral deposits. An early chapter emphasizes the importance of the proper collection and preparation of material for analysis, which is vital if subsequent analyses, however accurate, are to be correctly interpreted. The larger part of the book is devoted to a number of papers on the various analytical techniques available, including spectrochemical analysis, fluorescent X-ray, spectrography, mass spectrometric analysis, radiochemical methods, radioactivation analysis, and polarography. Structure determination by X-ray or neutron diffraction is not included, while only recent advances in the classical wet methods are discussed. Each chapter is supported by a copious list of references and there are numerous diagrams and figures. This book is a joint effort by the Department of Geology and Mineralogy at Oxford and AERE Harwell, and while primarily intended for geologists and chemists in the specialized field of geochemistry, will doubtless be of interest and value to many others concerned with analytical techniques.—G. E. Davies.

'*The World of Learning*'. 10th ed., 1959–60. 9¾ × 7½ in., pp.xiii + 1221. 1960, London: Europa Publications Limited. (Price £7.)

This impressive work which provides up-to-date information about educational, scientific, and cultural organizations all over the world is probably the most valuable guide of its kind ever produced. Each country is dealt with in remarkable detail under sections headed Learned Societies, Professional Associations and Research Institutes, Libraries and Archives, Museums and Art Galleries, and Universities. The information, sensibly arranged, includes notes of the contents of libraries, details of faculties and departments of universities, addresses, the names of leading officers of societies and the names of professors and other distinguished individuals, and the publications of learned societies. There is an introductory section containing international organizations and a 60-page index of organizations. One minor blemish is the absence of a consistent style for the names of societies: sometimes they are given in their original language, sometimes in English, sometimes, and more usefully; in both languages, but this is a small fault in an indispensable work.

—M. L. Pearl

NEW PUBLICATIONS

These titles are also available on index cards in advance of publication in the Journal, *each title being classified under the Universal Decimal system (UDC). Details and subscription rates can be obtained from the Secretary, The Iron and Steel Institute.*

American Foundrymen's Society (AFS). '*AFS Buyers Directory 1959–1961*'. 11¼ × 8½ in. pp.329. Illustrated. Des Plaines, Ill. 1960: The Society. (Price $10.00).

American Society for Testing Materials. '*ASTM Standards on Metallic Electrical Conductors*'. Sponsored by ASTM Committee B-1 on Wires for Electrical Conductors, Copper and Copper Alloys, Copper-covered Steel, Aluminium, Iron and Steel. 6th edition. 9 × 6 in., pp.x + 358. Illustrated. Philadelphia. 1960: The Society. (Price Members $3.60; Non-Members $4.50.)

American Society for Testing Materials. '*Report on Stress-Corrosion Cracking of Austenitic Chromium-Nickel Stainless Steels*'. S.T.P. No.264. 11 × 8½ in., pp.vi + 92. Illustrated. Philadelphia. 1960: The Society. (Price, Members $4.80; Non-Members $6.00.)

American Society for Testing Materials. '*Symposium on Newer Metals*'. Presented at the Third Pacific Area National Melting, San Francisco, 15 and 16 October, 1959. S.T.P. No.272. 9 × 6 in., pp.v + 218. Illustrated. Philadelphia, 1960: The Society. (Price, Members $5.80; Non-Members $7.25.)

Baker, H. W. (Editor). '*Modern Workshop Technology*'. Part II. 'Machine Tools and Manufacturing Processes'. 2nd ed. 8½ × 5½ in. pp.viii + 650. Illustrated. London, 1960: Cleaver-Hume Press Ltd. (Price £2 15*s*.)

Bauer, E. '*Elektronenbeugung*'. 8 × 6 in., pp. 233. Illustrated. München, 1958: Verlag Moderne Industrie. (Price DM.32.–)

Bernett, E. C. '*Short time, elevated temperature stress-strain behaviour of tensile, compressive, and column members*'. PB161492. 10½ × 8¼ in., pp.xii + 131. Illustrated. Washington, 1960: Office of Technical Services. (Price $2.75.)

Blanchard, P. A., Troiano, A. R. '*Hydrogen Embrittlement in Terms of Modern Theory of Fracture*'. PB161531. 10½ × 8 in., pp.iv + 26. Illustrated. Washington, 1960: Office of Technical Services. (Price $1.00.)

Bobtelsky, M. '*Heterometry*'. 9½ × 6½ in., pp. iv + 229. Illustrated. Amsterdam, London, 1960: Elsevier Publishing Company, D. Van Nostrand Co. Ltd. (Price £2 2*s*.)

British Standards Institution. '*Methods for the Analysis of Iron and Steel*'. Part 41: Lead in carbon steel and low alloy steel. BS1121: Part 41: 1960. 8¼ × 5¾ in., pp.8. London, 1960: The Institution. (Price 3*s*.)

British Standards Institution. '*Specification for Electroplated Coatings of Cadmium and Zinc on Iron and Steel*'. BS1706: 1960. 8¼ × 5¾ in., pp.20. Illustrated. London, 1960: The Institution. (Price 5*s*.)

British Standards Institution. '*Procedures for Obtaining Properties of Steels at Elevated Temperatures*'. Part 1. Proof Stress. BS3228: Part 1: 1960. 8¼ × 5¾ in., pp.8. London, 1960: The Institution. (Price 3*s*.)

Bunshah, R. (Editor). '*Transactions of the Vacuum Metallurgy Conference, New York University, June 1–3, 1959*'. 11 × 8½ in., pp.

x + 212. Illustrated. New York, 1960: New York University Press. (Price $7.50.)

CAMPBELL, J. E., ACHBACH, W. P. '*Current Tests for Evaluating Fracture Toughness of Sheet Metals at High Strength Levels*'. PB 151081. 10½ × 8 in., pp.66. Illustrated. Washington, 1960: Office of Technical Services. (Price $2.00.)

CANNING, W. AND CO. LTD. '*Handbook on Electroplating, Polishing, Bronzing, Lacquering*'. 19th ed. 9 × 6 in., pp.viii + 631. Illustrated. Birmingham, 1960: W. Canning & Co. Ltd. (Price £1 10*s*.)

CARPENTER, S. T., LINSENMEYER, R. F. '*Weld Flaw Evaluation*'. PB161322. 10½ × 8 in., pp.ii + 117. Illustrated. Washington, 1958: Office of Technical Services. (Price $2.75.)

CARWILE, N. L., ROSENBERG, S. J. '*A Study of 17–7 PH Stainless Steel*'. PB161089. 10½ × 8 in., pp.vi + 36. Illustrated. Washington, 1959: Office of Technical Services. (Price $1.25.)

CHALMERS, B., KING, R. '*Progress in Metal Physics*'. Vol.8. 9¾ × 6¼ in., pp.vii + 330. Illustrated. London, 1959: Pergamon Press. (Price £4 10*s*.)

CHAMBRE SYNDICALE DE LA SIDÉRURGIE FRANÇAISE. '*Annuaire*' 1960. 10¾ × 8¼ in., pp.271. [+16 p. in pocket at end]. Paris, 1960: M. Colomb. (Price, France 33 NF; outside France, 43 NF.)

CLIMAX MOLYBDENUM COMPANY. '*Atlas Hardenability of Carburized Steel*'. 7½ × 10 in., pp. 136. Illustrated. New York, London, 1960. The Company.

COLLINS, J. C. (Editor). '*Radioactive Wastes. Their Treatment and Disposal*'. With a foreword by Sir Alexander Fleck. 8½ × 5½ in., pp. xxi + 239. Illustrated. London, 1960: E. & F. Spon Ltd. (Price £2 15*s*.)

COMMUNAUTÉ EUROPÉENE DU CHARBON ET DE L'ACIER (C.E.C.A.) Haute Autorité – Bibliothèque. [EUROPEAN COAL AND STEEL COMMUNITY High Authority – Library] '*Automation 1949–1959*'. Bibliographies de la Haute Autorité – 19. 11½ × 8 in., pp.iv + 67. Luxembourg, 1959: La Bibliotheque.

'CORROSION PREVENTION AND CONTROL'. '*Anti-Corrosion Manual*'. 1960 ed. 11 × 8 in., pp. 404. Illustrated. London, 1960: Corrosion Prevention and Control (Scientific Surveys Ltd.). (Price £3.)

CRISCUOLO, E. L., CASE, D. P., POLANSKY, D. '*The Investigation of Radioisotopes for the Inspection of Ship Welds*'. PB161324. 10½ × 8 in., pp.iv + 57. Illustrated. Washington, 1958: Office of Technical Services. (Price $1.75.)

CS. VĚDECKA TECHNIKÁ SPOLEČNOST PRO HUTNICTVI – A SLÉVÁRENSTVI PRI ČSAV. VÝZKYMNÝ ÚSTAV MATERIALU A TECHNOLOGIE, PRAHA. 'Sbornik Defektoskopie Souber Přednášek přednesených na 'Dnech skoušení materiálu bez porušení' v Brno 1, a 2. března, 1956'. 8 × 5¾ in., pp.358. Illustrated, Prague, 1956: Matice Hornicko-Hutnicka.

DAUDEL, P. '*Radioactive Tracers in Chemistry and Industry*'. [English translation by U. Eisner of '*La radioactivité au service de la chimie et de l'industrie*', 1955]. 7½ × 5 in., pp. xi + 210. Illustrated, London, 1960: Charles Griffin & Co. Ltd. (Price £1 16*s*.)

DOLIWA, H. U. '*Gegossene Werkstucke*'. 9½ × 6½ in., pp.466. Illustrated. München, 1960: Carl Hanser Verlag. (Price DM. 61.–.)

EASTMAN KODAK COMPANY. '*Photomicrography of Metals*'. Kodak Publication No. P–39. 8½ × 5½ in., pp.44. Illustrated. New York. 1959: The Company. (Price $0.50.)

FIORENTINO, R. J., ROACH, D. B., HALL, A. M. '*Heat Treatment of High-strength Steels for Airframe Applications*'. PB151076. 11 × 8½ in., pp.84 + 10. Illustrated. Washington, 1959: Office of Technical Services. (Price $2.50.)

GALLACIO, A., CORNET, I. AMERICAN SOCIETY FOR TESTING MATERIALS. '*Report on Marine Atmosphere Exposure of Galvanic Couples involving Magnesium*'. S.T.P. No.255. 9 × 6 in., pp.26. Illustrated. Philadelphia, 1960: The Society. (Price, Members $1.80; Non-Members $2.25.)

HALL, W. J., GODDEN, W. G., FETTAHLIOGHLU, O. A. '*Preliminary Studies of Brittle Fracture Propagation in Structural Steel*'. PB 161325. 10½ × 8 in., pp.ii + 86. Illustrated. Washington, 1958: Office of Technical Services. (Price $2.25.)

HEDGES, E. S. (Editor.) '*Tin and its Alloys*'. 9½ × 7½ in., pp.viii + 424. Illustrated. London, 1960: Edward Arnold (Publishers) Ltd. (Price £6 6*s*.)

HONG, V. Y. S. '*Emulsifiable and Fire Resistant Rust Preventatives*'. PB161352. 10½ × 8 in., pp.iii + 68. Washington, 1959: Office of Technical Services. (Price $2.00.)

HORSTMANN, D. '*Der Einfluss von Aluminium in Eisen und in Zinkbad auf den Zinkangriff*'. Forschungsberichte des Wirtschafts-und Verkehrsministeriums Nordrhein-Westfalen, Nr.620. 11½ × 8¼ in., pp.29. Illustrated. Köln, 1958: Westdeutscher Verlag. (Price DM 9.40.)

HOT DIP GALVANIZERS ASSOCIATION. '*Hot Dip Galvanizing and Rust Prevention*'. 7½ × 5 in. pp.57. Illustrated. London, 1960: The Association.

HOUSE, J. W., FULLERTON, B. '*Tees-side at Mid-Century*'. 9½ × 7 in., pp.454. Illustrated. London, 1960: MacMillan & Co. Ltd. (Price £1 16*s*.)

HUGONY, E. '*Metallurgia*'. 9 × 6 in., pp.340. Illustrated. Milan, 1959: U. Mursia & Co. (Price L.1900.)

INSTITUTION OF METALLURGISTS. TAYLOR, J., BRADSHAW, A. V., ROBIETTE, A. G., ATTERTON, D. V. '*Progress in Metallurgical Technology*'. Lectures delivered at the Institution of Metallurgists Refresher Course. 1959. 8½ × 5½ in., pp.vii + 147. Illustrated. London, 1960: Iliffe & Sons Ltd. (Price 32*s*. 6*d*.)

INTERNATIONAL ELECTROTECHNICAL COMMISSION (C.E.I.) (COMMISSION ELECTROTECHNIQUE INTERNATIONALE – I.E.C.) '*International Electrotechnical Vocabulary*'. Group 40. Electroheating applications. [In English and French with terms in German, Spanish, Italian, Dutch, Polish and Swedish]. Publication 50 (40). 11¾ × 8¼ in., pp.vii + 40. Geneva, 1960: C.E.I. (Price Sw. Fr. 8.–.)

IVES, D. J. G. '*Principles of the Extraction of Metals*'. Royal Institute of Chemistry Monographs for Teachers. No.3. 8½ × 5½ in., London, 1960: The Royal Institute of Chemistry. (Price 6*s*.)

JONES, A. G. '*Analytical Chemistry*'. Some new techniques. 8½ × 5½ in., pp.vii + 268. Illustrated. London, 1959: Butterworths Scientific Publication. (Price £2.)

KASAK, A., CHANDHOK, V. K., DULIS, E. J. '*Development of High-Temperature Iron-Base Alloys*'. PB161337. 10¾ × 8¼ in., pp.vii + 62. Illustrated. Washington, 1959: Office of Technical Services. (Price $2.00.)

LAING, J., ROLFE, R. T. '*A Manual of Foundry Practice for Cast Iron*'. 3rd Edition. 8½ × 5½ in., pp.xi + 386. Illustrated. London, 1960: Chapman & Hall Ltd. (Price £2 10*s*.)

MELLGREN, A. '*Measuring Accuracy in Creep Tests. Part II. Influence of Thermal Stresses*'. PB161356. 10¾ × 8¼ in., pp.iv + 54. Illustrated. Washington, 1959: Office of Technical Services. (Price $1.50.)

MOON, D. P., SIMMONS, W. F. '*Methods for Conditioning Short-time tensile, creep, and creep rupture tests under conditions of rapid heating*'. PB151078. 10½ × 8 in., pp.38. Illustrated. Washington, 1959: Office of Technical Services. (Price $1.25.)

NEILSON, G. A. (Compiler) SHELL DEVELOPMENT COMPANY. '*Corrosion Data Survey*'. 1960 edition. 11 × 8½ in., pp. not continuously paginated. Emeryville, Cal., 1960: The Company. (Price £17 10*s*.)

NUNES, J., LARSON, F. R. '*Low Temperature Tensile-Hardness Correlations of SAE 4340 Steel*'. PB161467. 10½ × 8 in., pp.18. Illustrated. Washington, 1960: Office of Technical Services. (Price $0.50.)

OFFICE OF NAVAL RESEARCH U.S. DEPT. OF THE NAVY. '*Materials Research*'. A symposium. March 17–19, 1959. Philadelphia. 2 vols. PB161470; PB161471. 10½ × 8 in., pp. xxix + 386; v + 378. Illustrated. Washington, 1960: Office of Technical Services. (Price $6.00; $5.00.)

ORDNANCE MATERIALS RESEARCH OFFICE OFFICE OF ORDNANCE RESEARCH, U.S. ARMY. '*Proceedings of the Sixth Sagamore Ordnance Materials Research Conference, August 18–21, 1959*'. PB161443. 11 × 8½ in., pp.x + 549. Illustrated. Washington, 1960: Office of Technical Services. (Price $7.00.)

PHILIPCHUK, V. '*Explosive Forging*'. PB 161457. 10½ × 8 in., pp.18 + 40. Illustrated. Washington, 1960: Office of Technical Services. (Price $1.75.)

PLEINER, R. '*Základy slovanského železárského hutnictbí v českych semech*'. [The Foundation of Slavonic Iron Working in the Czech Lands] Ceskoslovenská Akademie Věd, Monument Archaeologica. Torus VI. 10½ × 8¼ in., pp.335 [+36; +5 maps in pocket]. Illustrated, Prague, 1958: Nakladatelství Ceskolovenské Akademie Věd. (Price 49 Kčs.)

REBUFFO, L. [ILVA – Alti Forni e Acciairie d'Italia] '*Italian Armour*'. [English edition]. 11¾ × 9¼ in., pp.18 + 112. Rome, 1960. Edindustria Editoriale S.p.A.

ROGERS, T. H. '*Marine Corrosion Handbook*'. 8 × 6 in., pp.xxi + 297. Illustrated. New York, London, 1960: McGraw Hill Publishing Co. Ltd. (Price £4 17*s*.)

SHANK, M. E. (Editor). WELDING RESEARCH COUNCIL. '*Control of Steel Construction to avoid Brittle Failure*'. Prepared by Plasticity Committee of the Welding Research Council. 9¼ × 6 in., pp.x + 184. Illustrated. New York, 1957: Welding Research Council.

SIEMENS, G. '*History of the House of Siemens*'. 2 vols. Translation by A. F. Rodger and L. N. Hole. 8¾ × 5½ in., pp.333, 326. Illustrated. Freiburg, 1957: Verlag Karl Alber.

SMALL, L. '*Hardness. Theory and Practice*'. Part I. Practice, 9 × 6 in., pp.xxv + 549. Illustrated. Ferndale (Michigan) 1960: Service Diamond Tool Company. (Price $8.50.)

SOCIETY OF CHEMICAL INDUSTRY. '*Corrosion Problem of the Petroleum Industry*'. A joint symposium, 26–27 November, 1959. London. S.C.I. Monograph No.10 8½ × 5½ in., pp. iv + 235. Illustrated. London, 1960: The Society. (Price £1 10*s*.)

SOCIETY FOR NON-DESTRUCTIVE TESTING. JOHNSON, P. D. (Editor). '*Symposium on the non-destructive testing of stainless steel brazed honeycomb structures*'. Presented in Chicago July 15–17, 1959. SNT Special Technical Publication No.100. 9 × 6 in., pp.xii + 281, Illustrated. Evanston, Ill. 1960: The Society. (Price $25.00.)

SOPHER, R. P., LOWE, Jr., A. L., RIEPPEL, P. J. '*Evaluation of Weld Joint Flaws as Initiating Points of Brittle Fracture*'. PB161323. 10½ × 8 in., pp.ii + 51. Illustrated. Washington, 1958: Office of Technical Services. (Price $1.50.)

STEIGERWALD, E. A., SCHALLER, F. W., TROIANO, A. R. '*The Lower Critical Stress for Delayed Failure*'. PB161532. 10½ × 8 in., pp.v + 30. Illustrated. Washington, 1960: Office of Technical Services. (Price $1.00.)

STEVEN, G., PHILIP, T. V. '*Development of a Corrosion-Resistant Bearing Steel for Service in Aircraft at Temperatures up to 1000°F*'. PB161338. 10¾ × 8¼ in., pp.viii + 60. Illustrated. Washington, 1959: Office of Technical Services. (Price $1.75.)

STRASSER, F. '*Practical Design of Sheet Metal Stampings*'. 9¼ × 6½ in., pp.viii + 175. Illustrated. Toronto; Philadelphia; London, 1959: Chapman & Hall Ltd. (Price £2 10*s*.)

UMOWSKI, J. S. '*Ferrous Metallurgy. Laboratory Manual*'. 10 × 7 in., pp.x + 83. Illustrated. Chicago, London, 1960: American Technical Society; The Technical Press Ltd. (Price £1.)

VEREIN DEUTSCHER EISENHÜTTENLEUTE Arbeitsgemeinshaft Walzwerktechnik. MULLER, Cr., LUEG, W., NÜRNBERG, W. '*Betriebsuntersuchungen an neuzeitlichen Block-Brammen-Strassen*'. Stahleisen-Sonderberichte. Heft 1. 11½ × 8 in., pp.72. Illustrated. Düsseldorf, 1960: Verlag Stahleisen. (Price DM. 16.–.)

WASSMANN, K. '*Einfluss der Schutzgasatmosphäre auf die Eigenschaften von Sinterstahl*'. Forschungsberichte des Landes Nordrein-Westfalen Nr.798. 11½ × 8¼ in., pp.94. Illustrated. Köln, 1959: Westdeutscher Verlag.

WEISS, H. '*Aufkohlung und Härtung von Sintereisen-Werkstoffen*'. Forschungsberichte des Landes Nordrhein-Westfalen Nr.799. 11½ × 8¼ in., pp.61. Illustrated. Köln, 1960: Westdeutscher Verlag.

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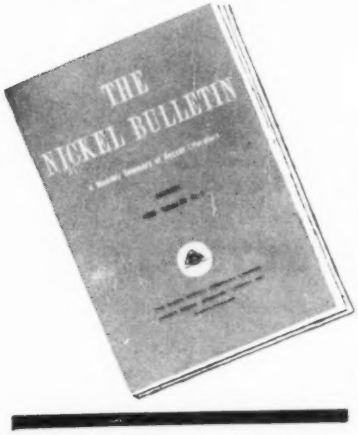

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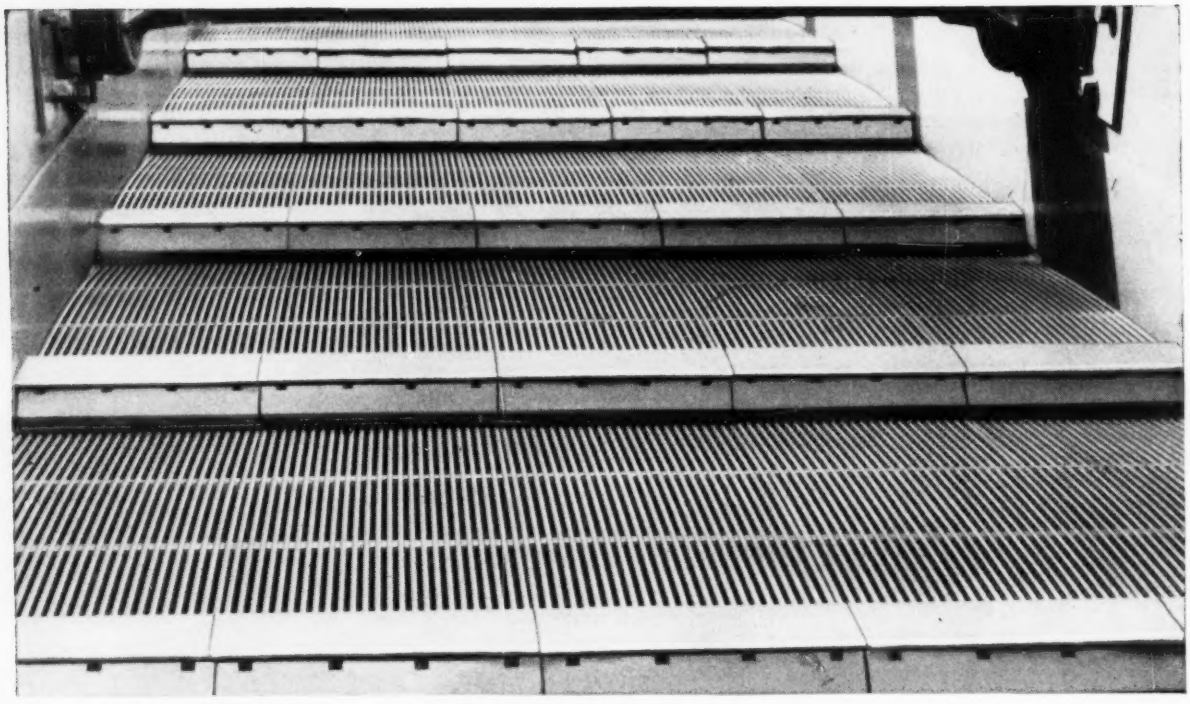

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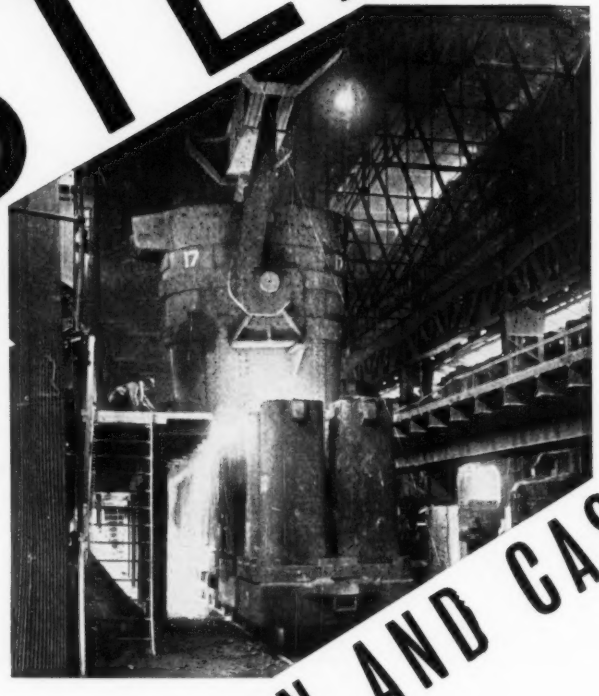

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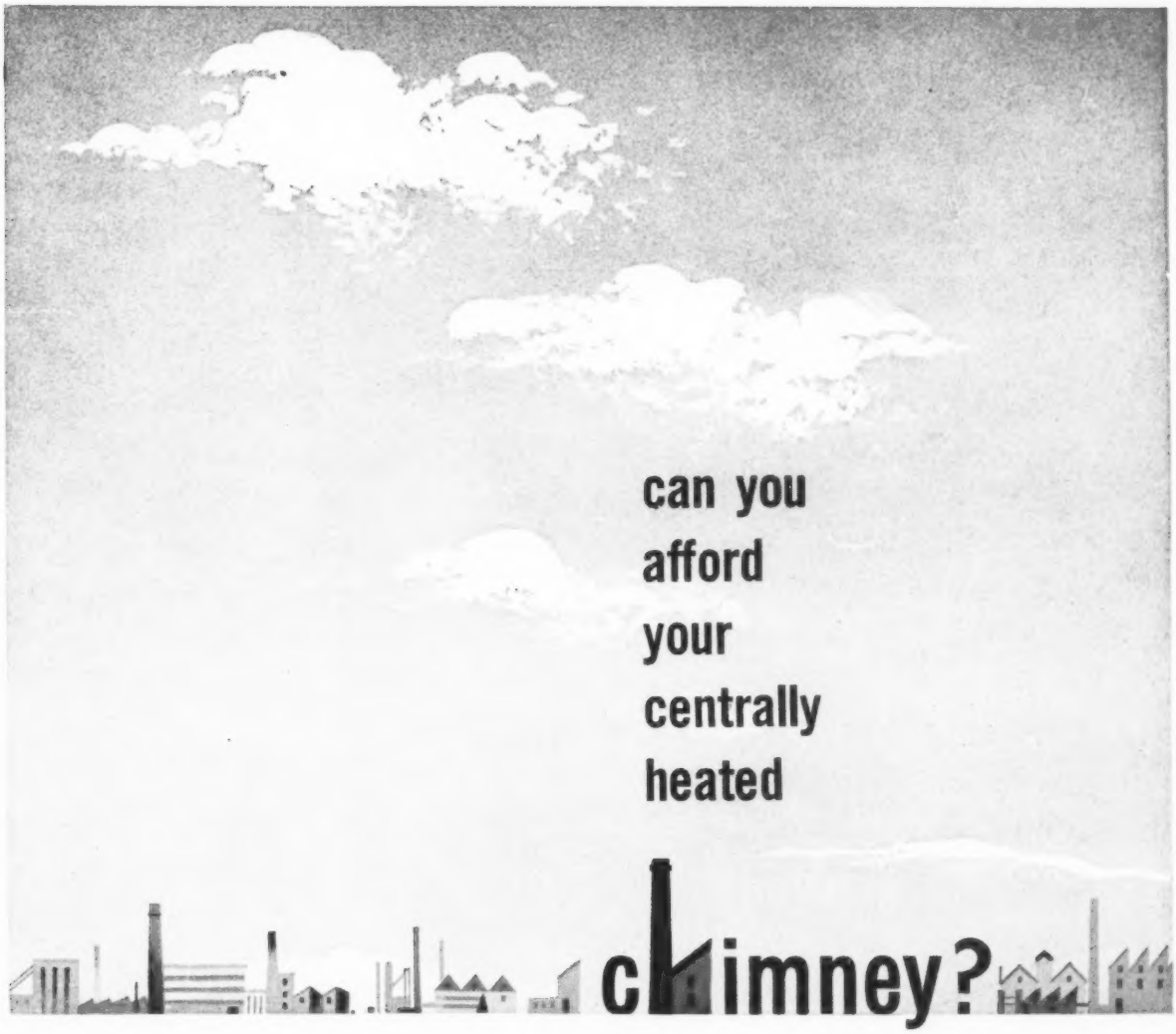

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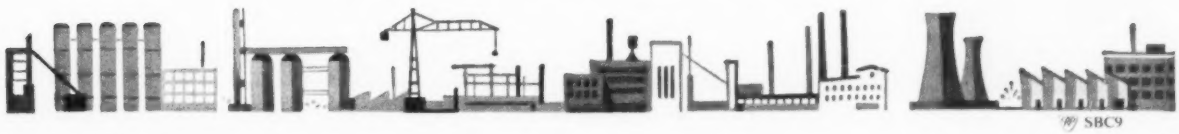

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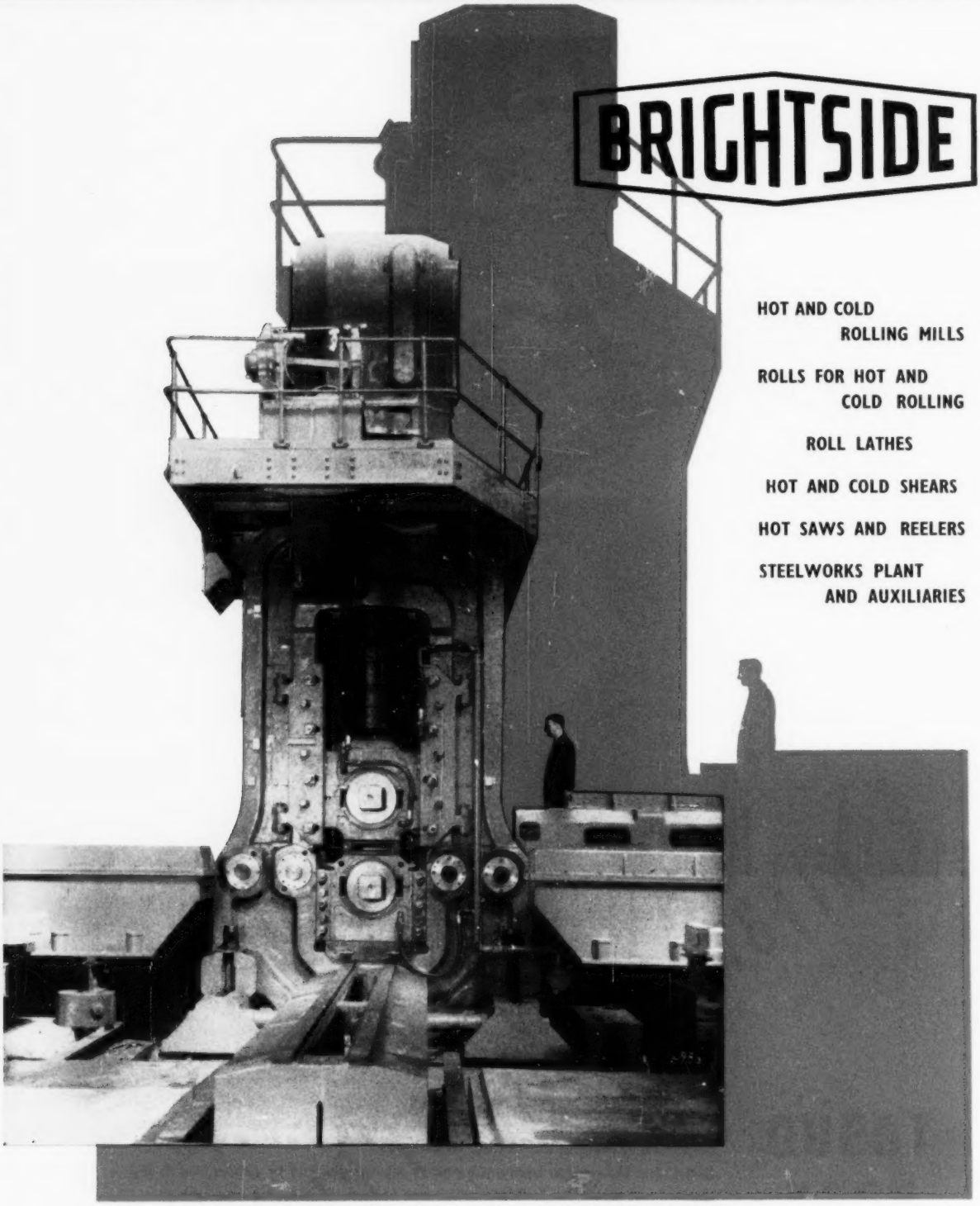

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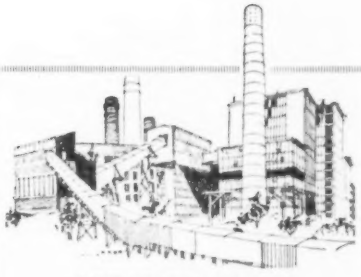

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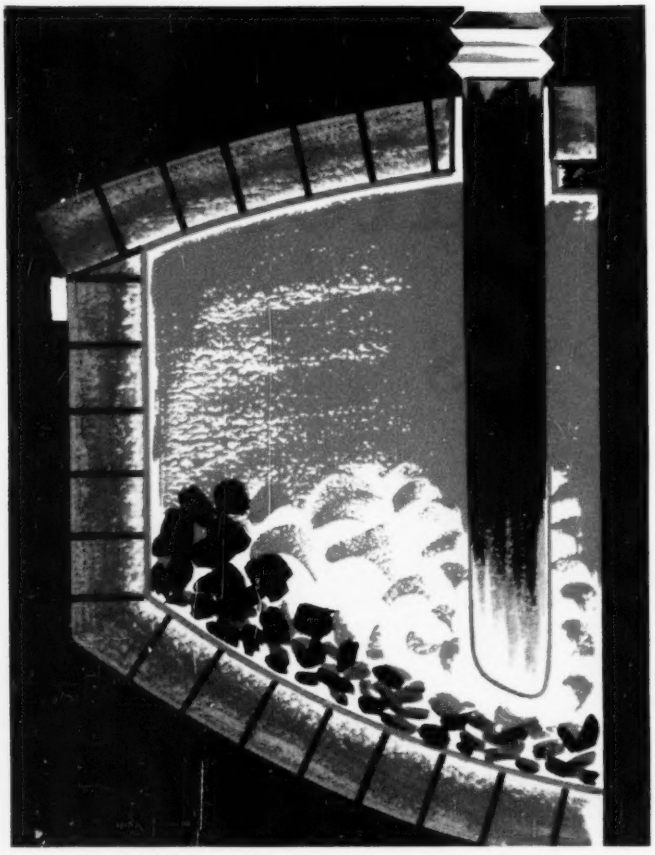

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FLEXIBLE RUBBER BLOCK COUPLINGS

CHOSEN BY
THE UNITED STEEL COMPANIES LIMITED

Appleby-Frodingham Steel Company
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Can accommodate limited angular and parallel misalignment.

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No end thrust on the bearings of the connected shafts.

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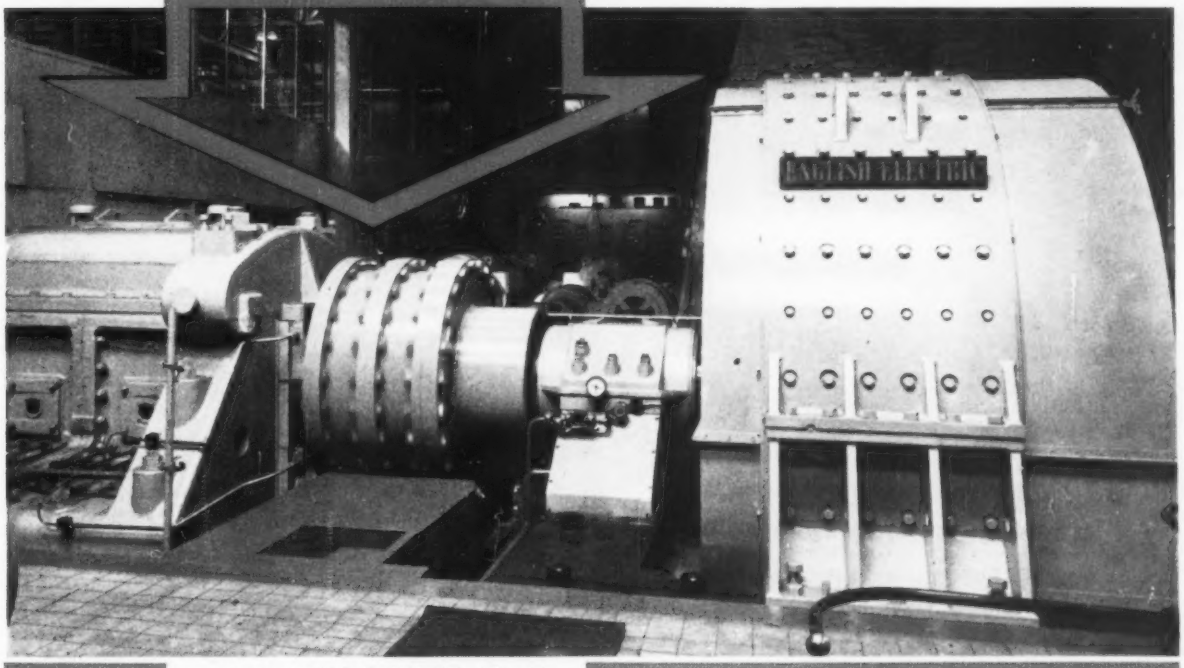

A size 600 H.P./R.P.M. Holset Flexible Rubber Block Coupling installed on the 40" Slabbing Mill at the Stocksbridge Works of Messrs. Samuel Fox & Company Limited

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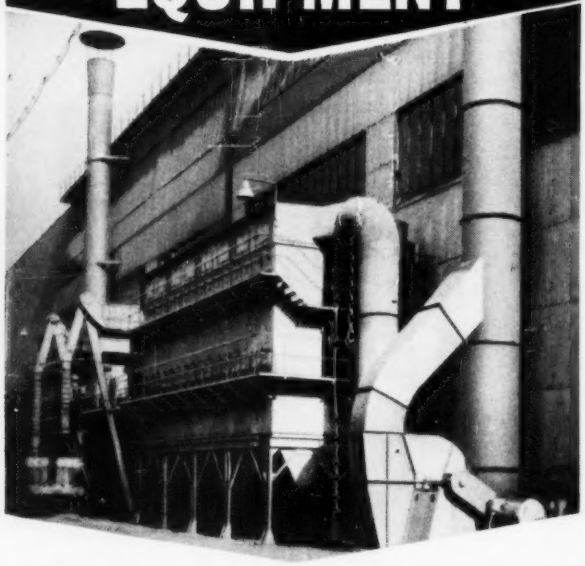

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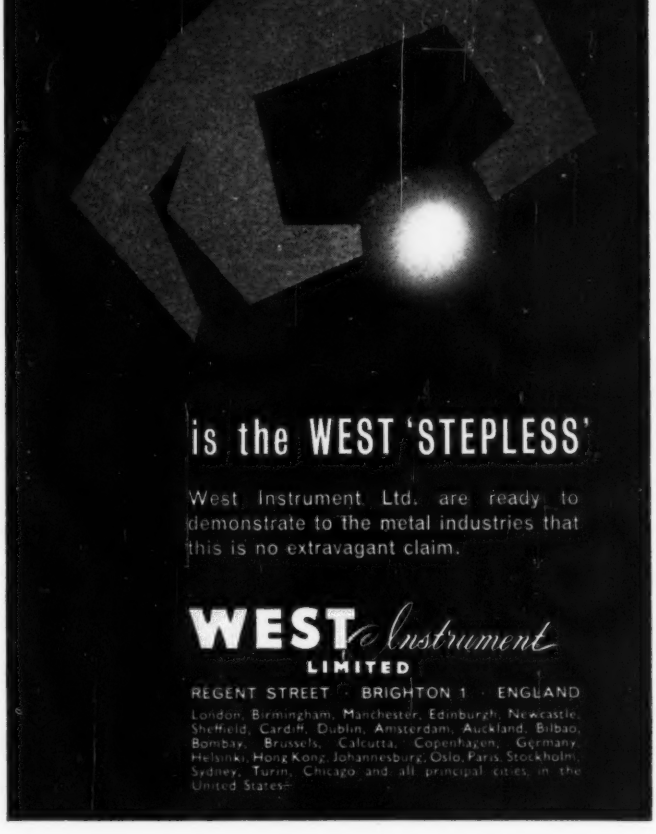

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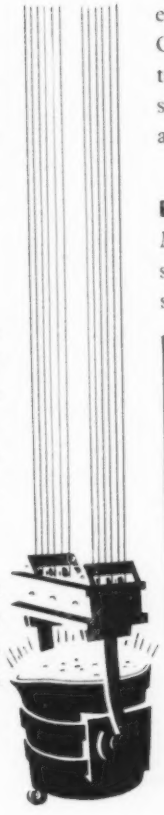

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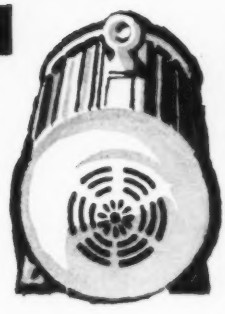

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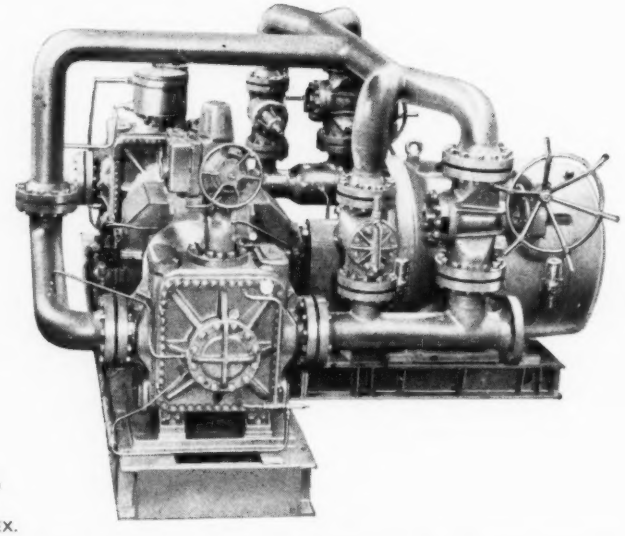

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Special Report No. 66

Sixth Report of the Corrosion Committee

The corrosion of iron and steel costs industry millions of pounds every year, and research on the best ways of saving this money is of the highest importance. The Sixth Report of the Corrosion Committee, which was founded in 1928 and is now administered by BISRA, has recently appeared as No. 66 in the Institute's Special Report series; it contains an account of the researches carried out during the past twenty years.

The Report covers the corrosion of iron and steel in air, in soil, and in water; it details the results of numerous experiments and recommends methods of protection against the many different forms of corrosion. Reports of tests carried out to ascertain the corrosion rates of different kinds of bare irons and steels all over the world, and of steels protected with paint and/or metal coatings, are given.

Two other interesting researches described in the Report concern the corrosion and protection of steel at elevated temperatures up to 350°C, and marine corrosion. As a result of the latter, several reliable anti-corrosive compositions have been formulated, some of which are in use on H.M. ships and the "Queens".

The Report, which consists of 228 octavo pages, illustrated with 20 line and 21 half-tone figures, and bound in cloth with stiff board covers, costs £3 3*s*. 0*d*. (postage 1*s*. 0*d*.), and may be obtained from:

The Secretary, The Iron and Steel Institute,
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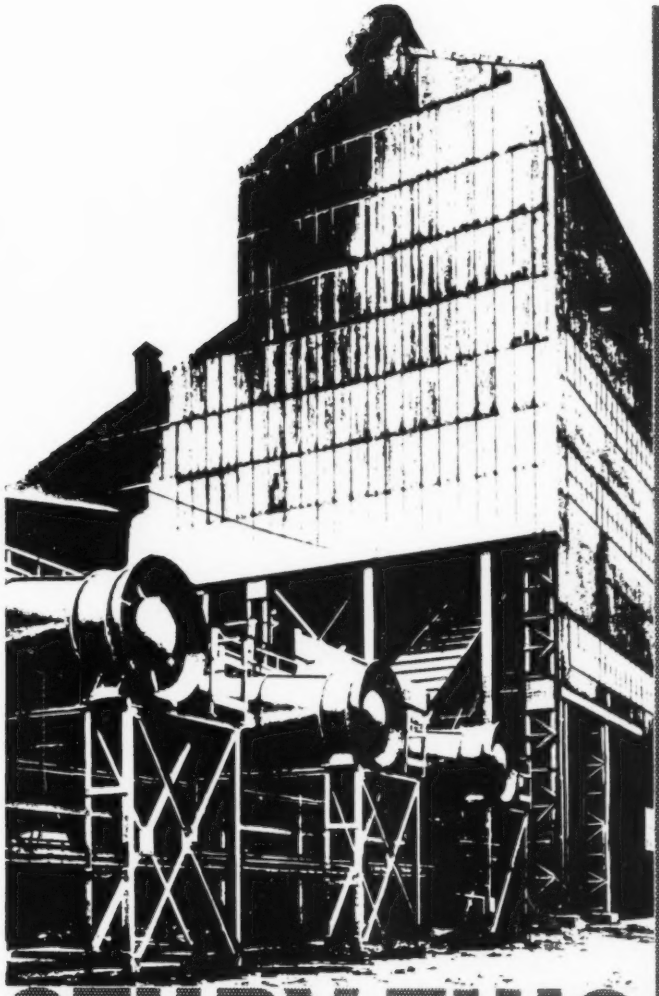
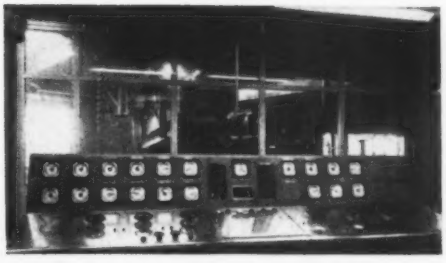
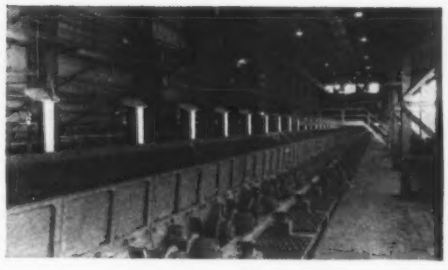


The Igniter



Sinter Process Control Desk



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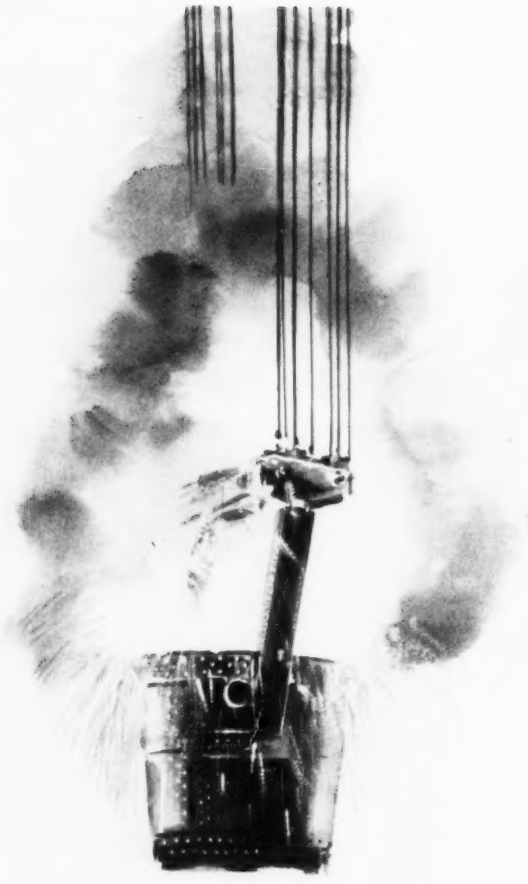

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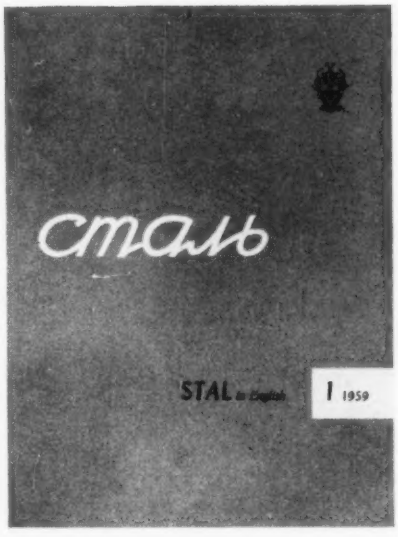

By arrangement with the Department of Scientific and Industrial Research, The Iron and Steel Institute is now publishing monthly a complete English-language version of STAL (*Steel*), the major Russian periodical in the field of iron and steelmaking technology. The developments reported in *Stal in English* are of the greatest interest to everyone connected with iron and steelmaking.

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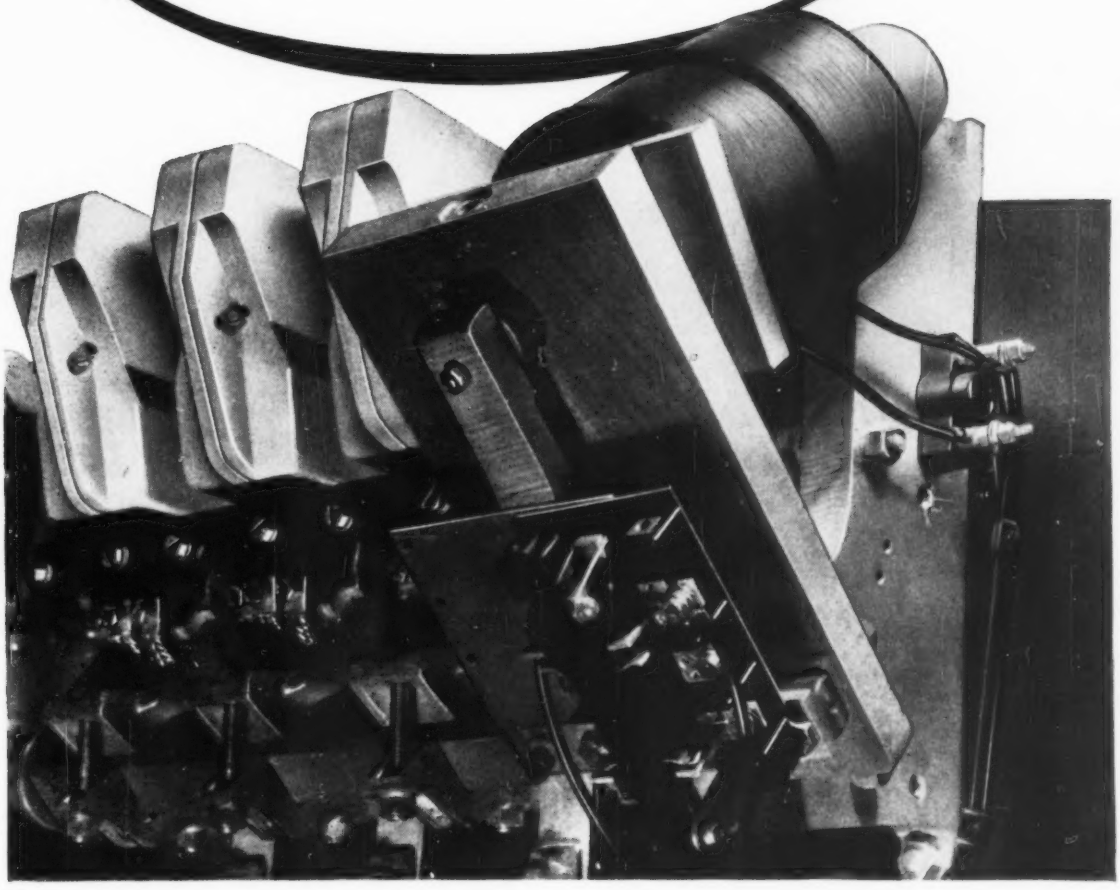

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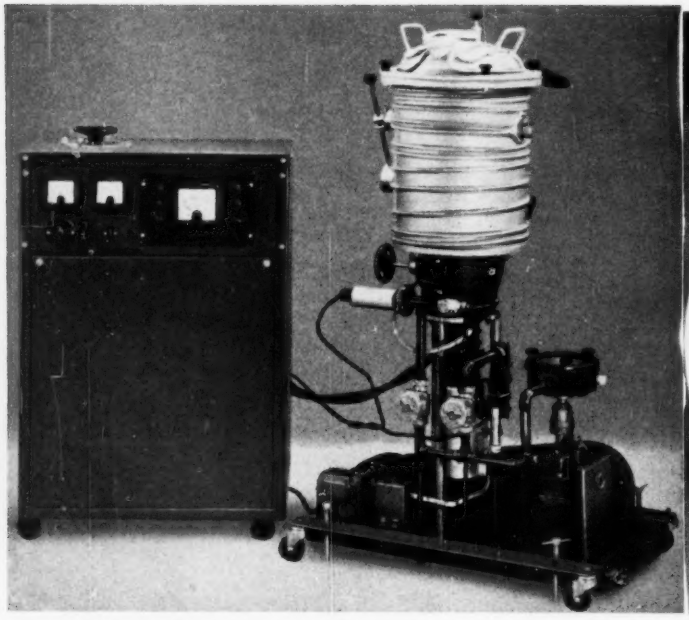

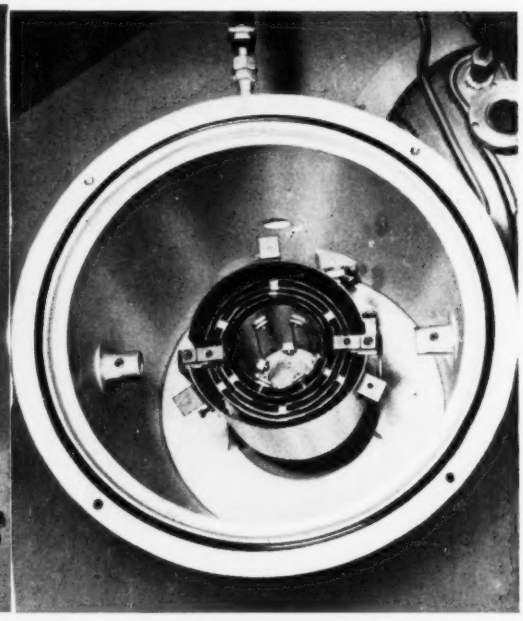

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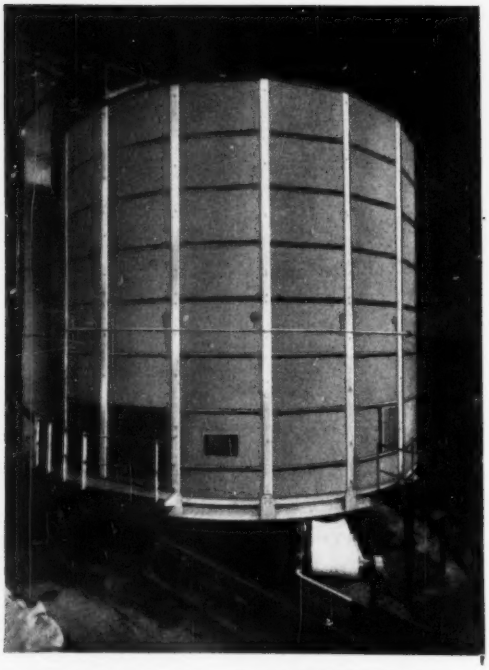

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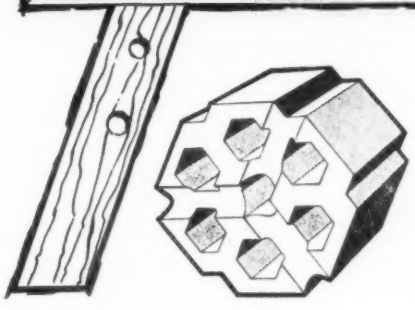

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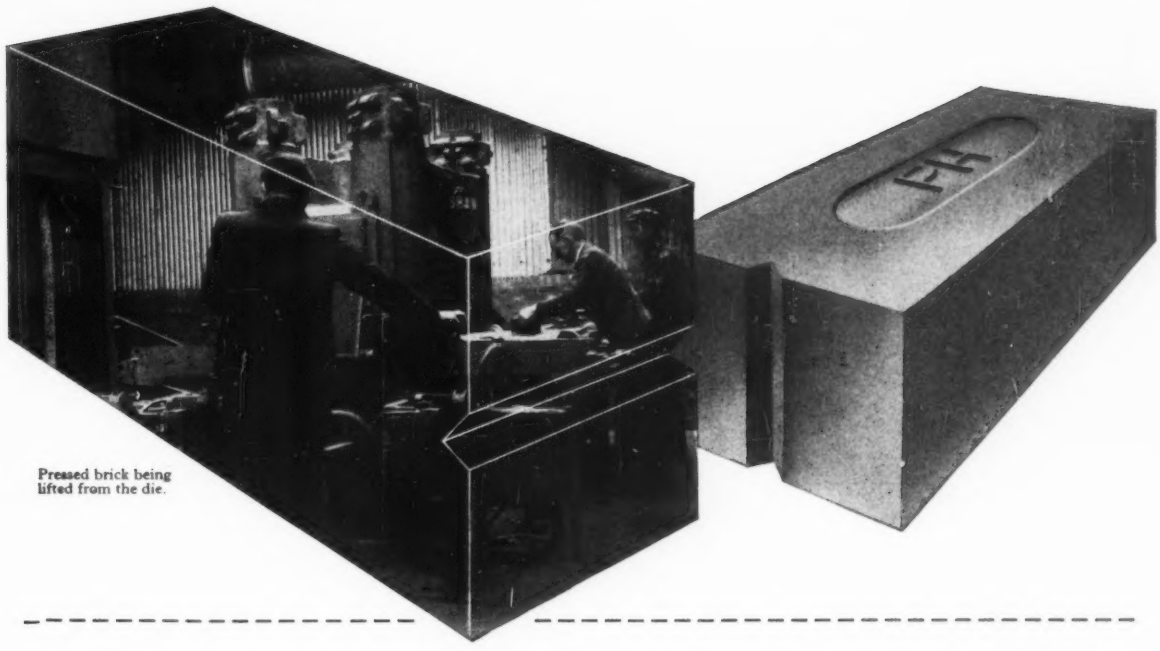

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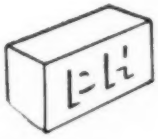

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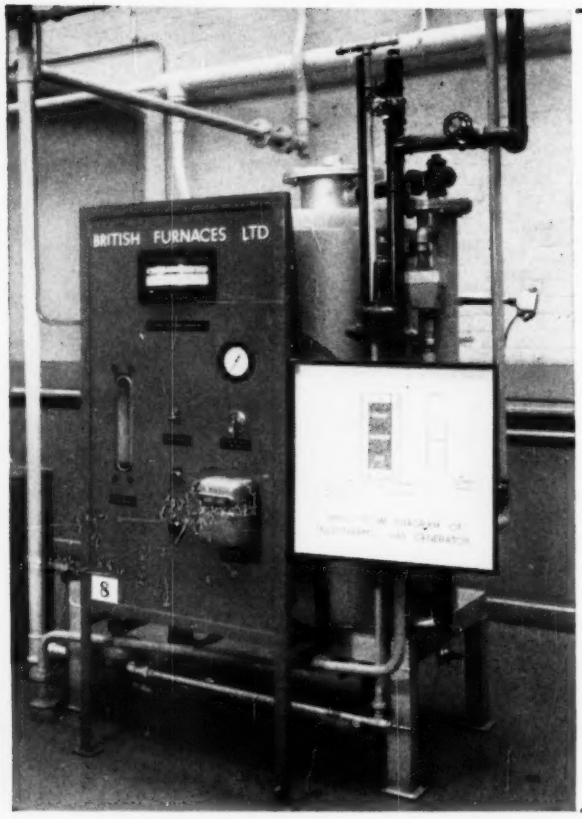

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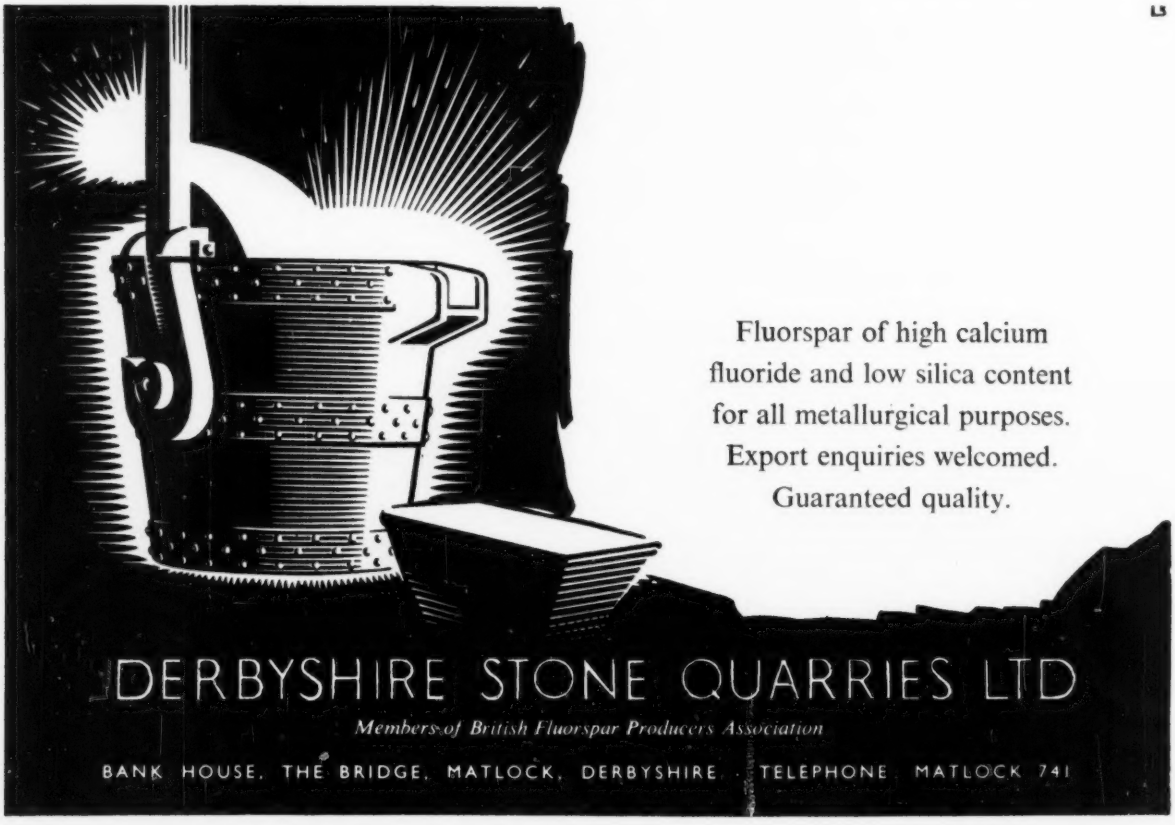

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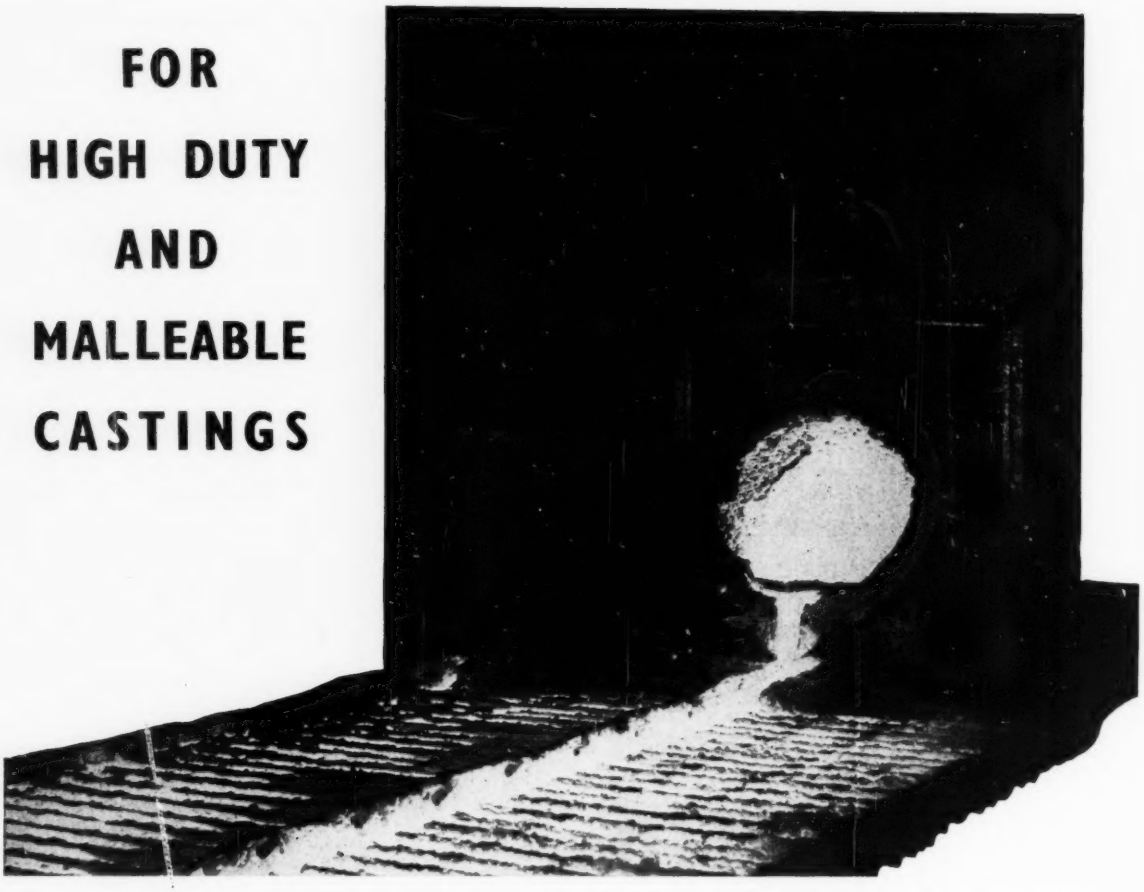

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GRADES:	A	B	C	D	E	F	G
SILICON%	1·9–2·1	1·4–1·6	0·9–1·1	2·25–2·5	0·9–1·1	1·4–1·6	1·9–2·1
SULPHUR%	0·06	0·07	0·08	0·05	0·08	0·07	0·06
PHOSPHORUS%	0·6–0·7	0·6–0·7	0·6–0·7	0·4–0·5	0·25	0·25	0·25
MANGANESE%	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5
TOTAL CARBON%	2·7–3·0				2·8–3·1		

In addition to the above other grades of Dale Refined Iron can be supplied to meet more exacting demands which call for alloy additions and special processing.

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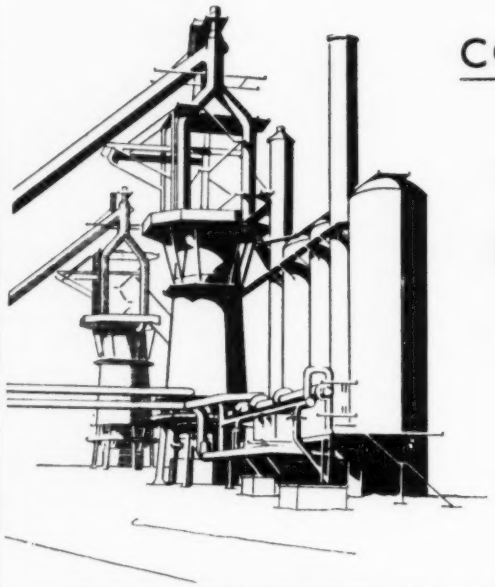

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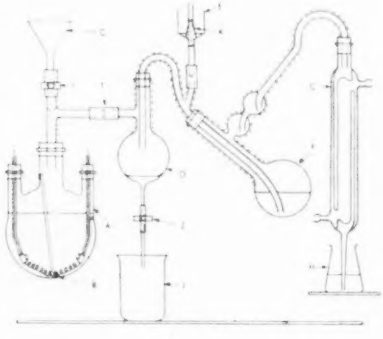

Great interest has always been shown in the role of nitrogen in determining the properties of ferrous alloys. Reliable and accurate methods are therefore necessary for determining the content of this element in alloys.

The establishment of the reproducibility and accuracy of analytical methods to serve as routine or reference procedures for the many alloys now produced is a major undertaking. It was for this reason that the Nitrogen Group of the Steelmaking Division of the British Iron and Steel Research Association was set up eight years ago. The Report of the Group has now been published as No. 62 in The Iron and Steel Institute's Special Report Series. The information it contains will be of inestimable value to all those interested in this subject.

The Report, which comprises 160 quarto pages and a number of illustrations, is bound in cloth with stiff covers, and costs £1 17*s.* 6*d.* (Members £1 5*s.* 0*d.*). It may be obtained from:—

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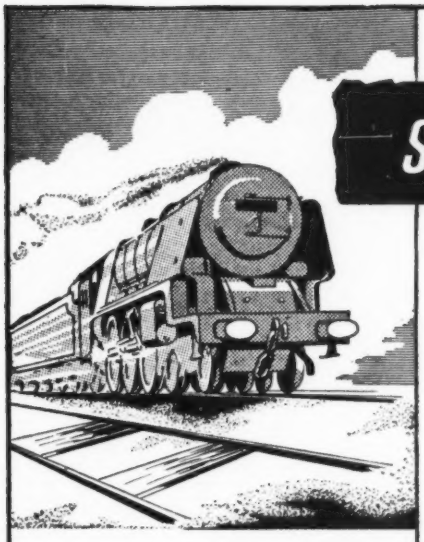

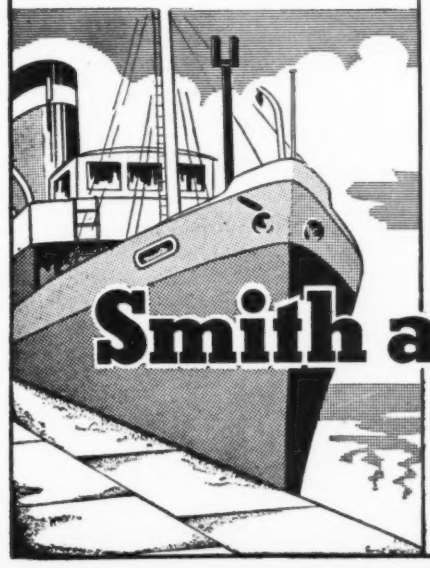

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Published at the offices of The Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1., and
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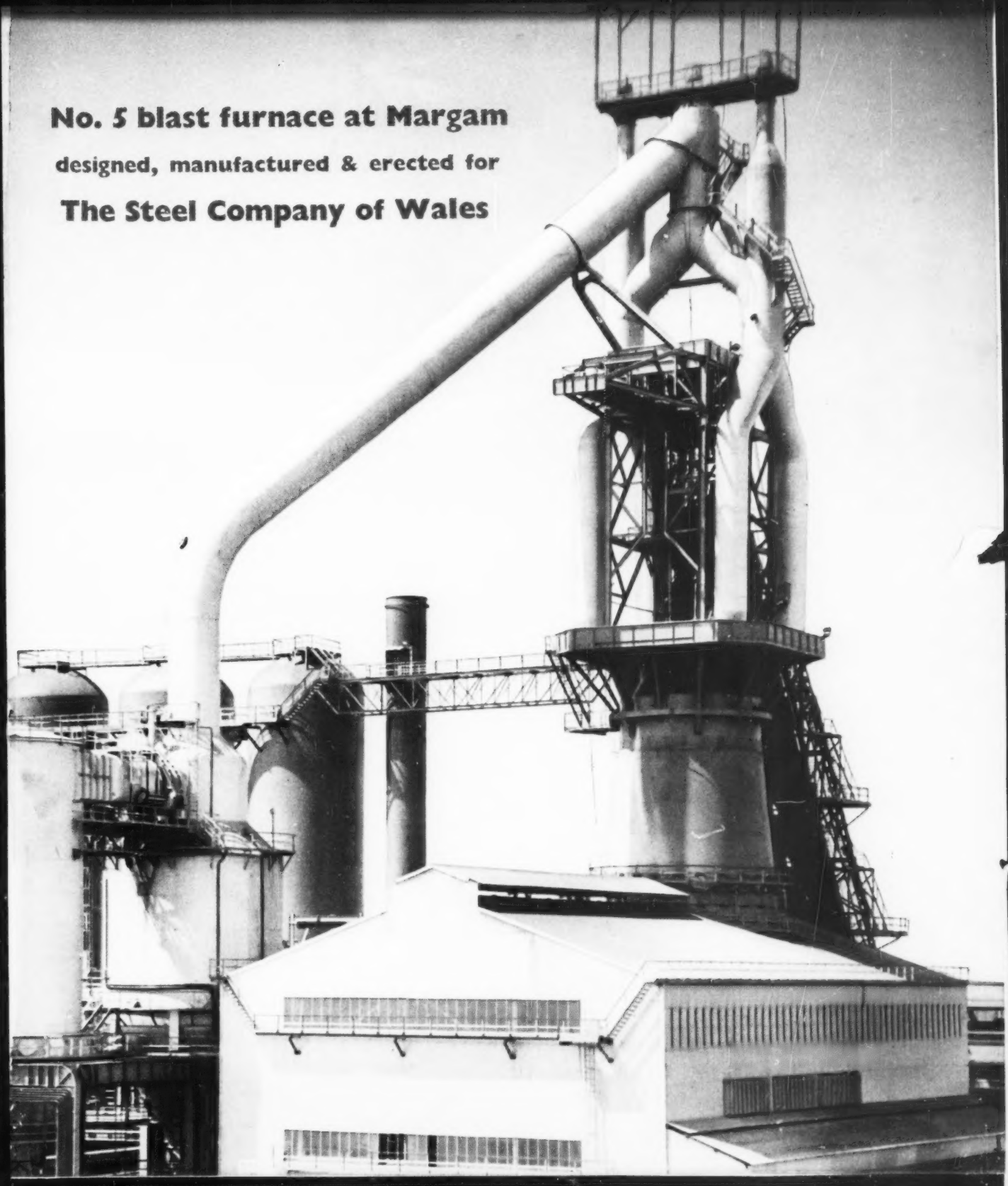

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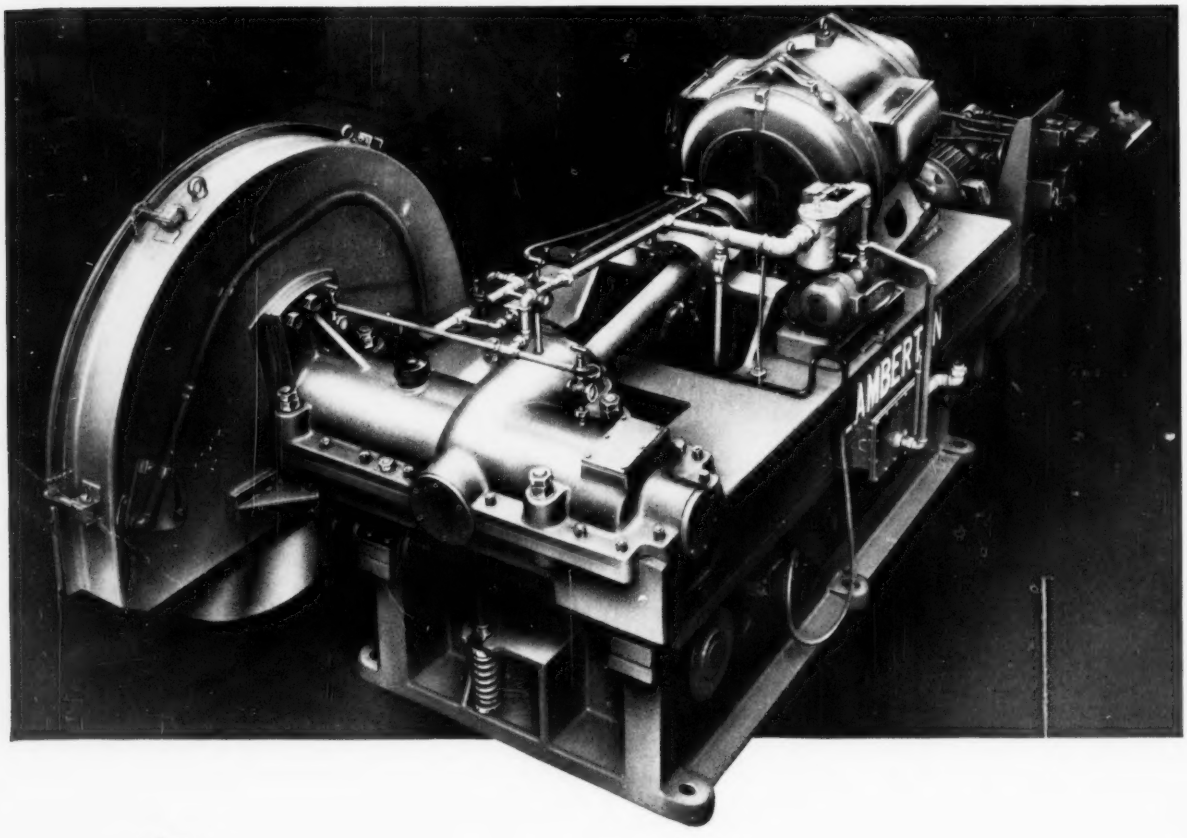

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